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D19
8 Reports on the Realisation and Validation Analysis of the Demonstration Buildings in BRITA in PuBs

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Lead contractor name for this deliverable and organisation:
Marco Citterio
ENEA

Project coordinator name and organisation:
Hans Erhorn
Fraunhofer Institute of Building Physics

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PU	Public	**X**
PP	Restricted to other programme participants (including the Commission Services)	
RE	Restricted to a group specified by the consortium (including the Commission Services)	
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D19
8 Reports on the Realisation and Validation Analysis of the Demonstration Buildings in BRITA in PuBs

Editor and main author:
Marco Citterio (ENEA, I)

Demonstration project chapter authors:
Juergen Goerres, Nina Weiss, Sandra Langer (City of Stuttgart, DE)
Gilbert Snook (City College Plymouth,UK)
Jan Rolland (Asker Municipality, N)
Harald N. Røstvik (Sivilarkitekt Røstvik AS, N)
Ove Mørck (Cenergia, DK)
Pavel Charvat, Miroslav Jicha (Brno University of Technology, CZ)
Saulius Raslanas (Vilnius Gediminas Technical University, LT)
Moissis Kourouzidis (Evonymos Ecological Library)
Euphrosyne Triantis (NTUA, GR)

Disclaimer:

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Content

Preface

The BRITA in PuBs project is an EU-supported integrated demonstration and research project that aimed at increasing the market penetration of innovative and cost-effective retrofit solutions to improve energy efficiency and implement renewable energy in public buildings all over Europe. Firstly, this shall be realised by the exemplary retrofit of 8 demonstration public buildings in four European regions (North, Central, South, East). By choosing public buildings of different types such as colleges, cultural centres, nursing homes, student houses, churches etc. for implementing the measures it was easier reach groups of differing age and social origin. Secondly, the research issues included a socio-economic research study identifying real project-planning needs, financing strategies, the development of design guidelines, the development of an internet-based knowledge tool on retrofit measures and case studies and a quality control-tool box to secure a good long-term performance of buildings and systems.

Bringing Retrofit Innovation to Application in Public Buildings – BRITA in PuBs was therefore a leading project within the EU ECO-BUILDINGS programme. The ECO-BUILDING concept is expected to be the meeting point of short-term development and demonstration in order to support legislative and regulatory measures for energy efficiency and enhanced use of renewable energy solution within the building sector, which go beyond the Directive of the Energy Performance of Buildings (EPBD).

0. Demonstration Building Results Summary

Author: Marco Citterio – WP5 Leader

0.1 Executive Summary

This document summarizes the results of WP5 pf BRITA in PuBs and aims to give quick information about how Demonstration Buildings achieved target fixed for this project. Detailed information can be achieved in 8 final reports.

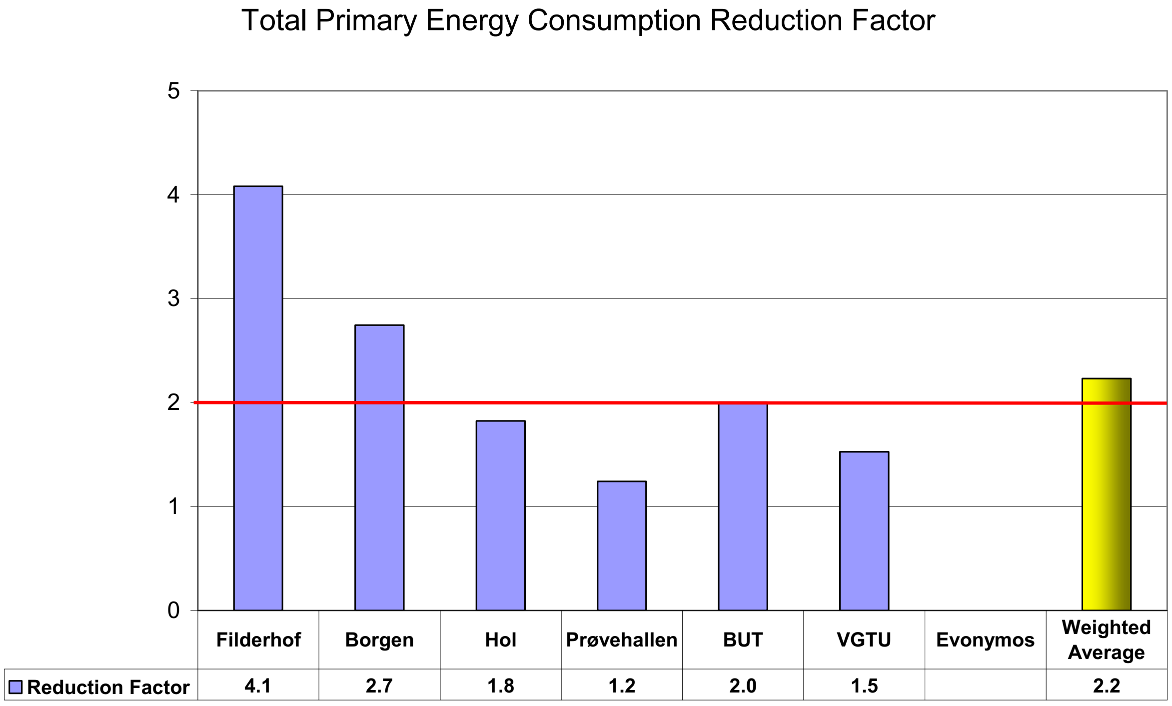
The demonstration buildings are located in four climatic and economic areas (North, Central, East and South) into which the project was divided:

Filderhof (Stuttgart – DE)
City College Plymouth (Plymouth – UK)
Borgen Community Centre (Asker – NO)
Hol Church (Hol – NO)
Prøvehallen (Copenhagen – DK)
Brewery (Brno – CZ)
VGTU (Vilnius – LT)
Evonymos (Athens – GR)

Goals of the project were the reduction of a factor 2 of primary energy consumption and of the percentage of dissatisfied persons.

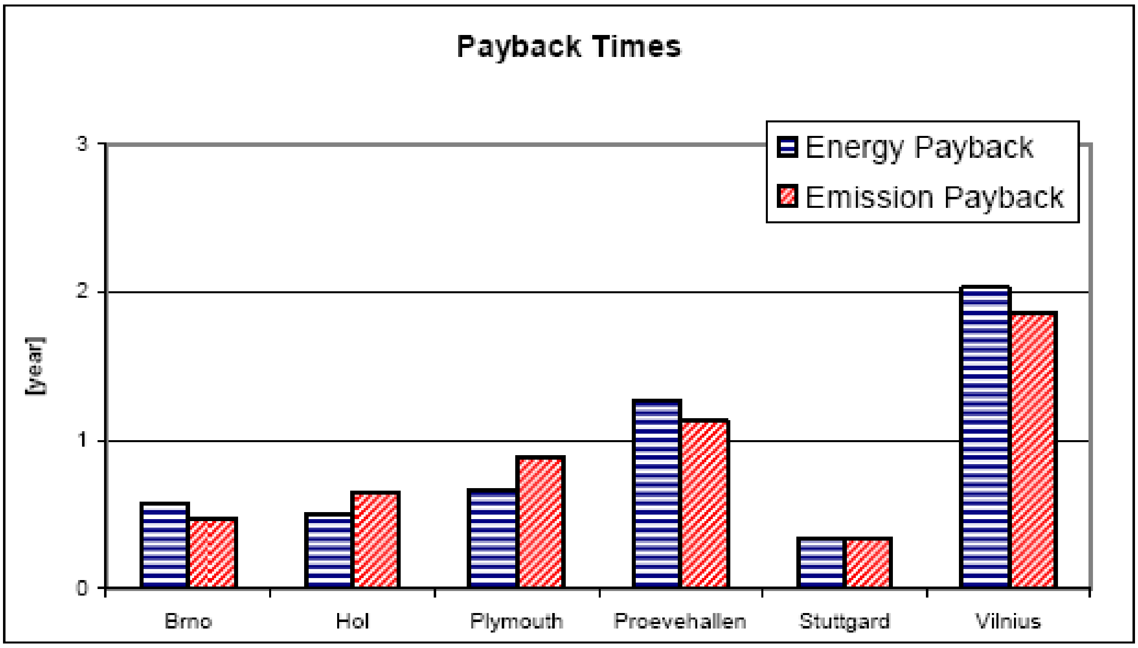
The goal of reduction of Primary energy consumption was reached by the majority of the demonstration building. The weighted average of PE reduction Factor, calculated on the basis of the heated area of different building is higher than 2.

The result of Demonstration Building Evonymos is not reported in this graph because the very high value of Primary Energy Reduction Factor reported (6.3) was strongly affected by not reasonable values of before retrofit Electric Energy consumption (140 kWh/m^2 a).



The goal of improvement of thermal comfort was substantially reached, but it was not possible to provide a common representation of the results of this parameter. For this important item, please refer to detailed reports.

Demonstration partners developed, in cooperation with University of Palermo, Life Cycle Assessment of their interventions. The main result of this analysis was that all the intervention present a good energy and emission payback, as the following graph clearly shows.



In conclusion, looking at energy and environmental results, BRITA in PuBs was a successful project.

Demonstration partner made a big job in documentation of all the steps of their projects, since the planning to the monitoring and analysis phase. These information are now available for all the interested decision makers and professionals. It has to be underlined that the availability of these information arrives on the stage at the right moment, when the interest for the energy efficiency, in particular of buildings, is at its top since decades all around Europe.

All demonstration partners learned a lot from this experience and being in a framework of an Integrated Project gave to all of them the possibility of sharing ideas and experiences.

0.2 Introduction

This report is the final product of WP5 (Demonstration Buildings) of BRITA in PUBs project. Aim of this report is to document the evaluation phases of 8 demonstration buildings realized throughout the working period of BRITA. The design phase of the energy saving retrofit concepts of the demonstration buildings is documented in the report D8[a].

This report is written in a period of dramatic increasing of energy prices: prices of oil and all energy sources are changing weekly, so most of the economic evaluations could result not updated in few months. The effort of this summary is then trying to make evaluation that could remain valid at time of reading, facing what is happening in this sector.

As already mentioned in previous report on Design Phase[a] the demonstration buildings in BRITA in Pubs project were originally 9, but the Italian demonstration project (Daniel's) was cancelled due to lack of funding for major refurbishment. Further, the British demonstration project (City College Plymouth) was strongly reduced when the refurbishment of the Tower Block was cancelled: it was agreed with the BRITA-in-PuBs Steering Group and the Commission that the college should remain a demonstration partner and provide full information for the Wind Turbines which were installed.

In spite of great difficulties encountered during both the design and construction phases (at least two other buildings - besides the Italian and British ones - were very close to cancel their participation to the project), all remaining projects have realized what foreseen at the beginning in due time. Some minor changes were agreed with the Commission and reasons for them are well documented in detail in the final reports.

Goals of the project were the reduction of a factor 2 of primary energy consumption and of the percentage of dissatisfied persons. The energy related goal has been largely achieved by 3 of buildings, two of them were close to the target, one (Prøvehallen) reported 20% only of reduction. The reason for that was the success of the building: electric energy consumption was reported higher than expected because the big success of the building as location for dramas and music events. Because some of the buildings changed their use assignment in between (before and after the refurbishment period), the comparison of energy consumption was done with reference buildings.

The comfort related goal was substantially achieved by all buildings: users reported significant improvement where the use of building did not change.

0.3 The buildings

0.3.1 Typologies

The 8 demonstration buildings of BRITA in Pubs are representative of a large amount of buildings around Europe: they cover social and cultural centre, school, university, nursing home, church, library. According to what defined at the beginning of the project, in Europe can be found more than 500.000 buildings comparable to these demonstration buildings.
The following table summarizes building typologies and the amount of comparable buildings that can be found throughout Europe.

Name	Country	Typology	No. of comparable buildings
Filderhof	Germany	Nursery home	18000
Plymouth City College	UK	Education and research	300000
Borgen Community Centre	Norway	Local Community Centre	6000
Hol	Norway	Church	180000
Prøvehallen	Denmark	Public Cultural Centre	3000
Brewery	The Czech R.	University Cultural Centre	1000
VGTU	Lithuania	University	5000
Evonymos	Greece	Library	4000

0.3.2 Technologies

Demonstration Buildings in Brita in Pubs adopted a large amount of advanced technologies in the following fields: Energy Conservation, Renewable, Energy Efficient Supply and Controls. In the following tables is summarized who adopted what. As the Plymouth City College project has only realized the wind turbine, it is not listed in the following technology overview tables

Energy conservation

	envelope insulation improvement	**windows replacement**	**joints sealant**	**daylighting**	**artificial lighting improvement**	**hybrid ventilation**	**thermal mass exposition**	**culvert**	**solar shading**	**heating plant improvement**	**heat recovery**	**hot water saving measures**
Filderhof	x	x		x	x	x						
Borgen	x	x		x	x	x		x			x	
Hol	x	♦		x			x					
Prøvehallen		x		x	x	x						x
Brewery	x	x		x		x						
VGTU		x	x							x		
Evonymos	x	x		x					x			

♦ Windows replacement was not possible due to constraints from antiquarian Authorities, windows were improved by means of gaskets installation.

	Renewables					**Energy Efficient Supply**				
	solar collectors	**PV**	**wind generator**	**solar air heating system**	**sunspaces, passive gains**	**CHP**	**district heating**	**heat pump**	**geothermal**	**boiler replacement**
Filderhof	x	x			x	x				x
City College Plymouth			x							
Borgen	(x)							x	x	
Hol		x		x						
Prøvehallen		x		x			x	x		
Brewery	x	x						x		x
VGTU										
Evonymos		x			x					x

(x) It was planned to be a demo collector, but was never finished in time to mounted at Borgen

	Materials		**Advanced Controls**				
	ecological	**LCA**	**BEMS**	**thermal loads**	**Ventilation**	**lighting**	**solar shading**
Filderhof	x	x	x			x	
Borgen		x			x	x	
Hol	x	x					
Prøvehallen		x	x	x	x	x	x
Brewery	x	x	x		x		
VGTU		x	x				
Evonymos					x	x	x

0.3.3 Dimensions

Name	Country	Floor area (m^2)	Glazed area (m^2)	Volume (m^3)
Filderhof	Germany	2131	161	8964
Borgen	Norway	9049	750 398 (*)	42236
Hol	Norway	550	28	6150
Prøvehallen	Denmark	1809	220	15700
Brewery	The Czech R.	2660	145	10880
VGTU	Lithuania	8484	1089	25710
Evonymos	Greece	1000		

(*) Skylight

0.3.4 Climates

The 8 buildings are located in four climate region in which the project was divided: North (3), Central (2), East (2) and South (1) Europe.

Name	Country	Standard Winter Av. Temp. °C	Standard Degree Days	Degree Days 2007-08	Difference %
Filderhof	Germany	5.8	3555(*)	3351	- 5.7
Borgen	Norway				
Hol	Norway	-7.3	5620	5860	+ 4.2
Prøvehallen	Denmark	4	3215 (*)	2445	- 24
Brewery	The Czech R.	3.6	3210 (*)		
VGTU	Lithuania	- 4	4005 (*)	3047	- 24
Evonymos	Greece	11.6	1110		

(*) Internal Temperature Base = 18°C

Table shows how the monitoring period was warmer than usual, especially in Denmark and Lithuania. All monitored heating energy consumption were then climate corrected in order to allow the right comparison to standard conditions.

0.4 Results

Most of buildings were monitored during the last year (April 2007 – April 2008), but some of them collected more than year of data. VGTU, for instance, monitored all the 4 years of project duration, it is then possible to follow the evolution of energy consumption and the influence of different measure application on building energy performance. Detailed analysis is described in the report. Results reported by Demonstration partner are analyzed and compared in following paragraphs.

0.4.1 Life Cycle Assessment

Life Cycle Assessment was conducted in almost all projects and the final detailed report[b] is available on BRITA website. Here a summary of the conclusions of the study. The analysis showed significant energy and environmental convenience of the accomplished retrofits[1]. In particular, the energy and environmental payback times that resulted were very low, with values varying from 0.3 to 2 years (Figure 0-1). This means that in a relatively small time period, the global energy and environmental investments are fully repaid by the obtained benefits. The relatively long useful time of the retrofits therefore produces large energy consumption savings and avoidance of emissions of large quantities of pollutants.

It is interesting to note that the largest benefits are generally related to the insulation of the buildings: high efficiency windows, mineral wool, and glass wool sheets, in fact, insulation allows great energy savings over a long period with a relatively short life-cycle impact (Figure 0-2). Even renovation of heating plants and lighting systems produces large benefits. In contrast, the use of renewable energy had lower benefits due to the low productivity of plants, with outputs sometimes lower than expected at the design stage.

To summarize all of the global energy benefits, it is also interesting to observe the Energy Return Ratio Index that shows how many times the life-cycle energy consumption is repaid by the overall energy benefits (Figure 0-3). Results showed an average of about 30 times, with values generally higher than 10 times and an optimum close to 60 times.

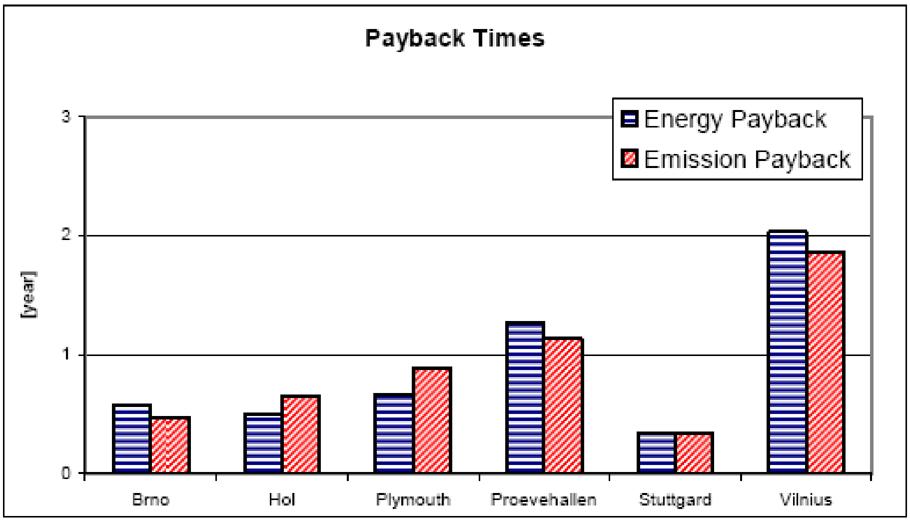


Figure 0-1 Payback times

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[1] The Borgen case study has been excluded by the comparison to other demo-building actions, because it was not possible to split data concerning retrofit from data concerning the construction of new building parts. Results referred to this case study are therefore not comparable. Evonymos did not present data for developing LCA study.

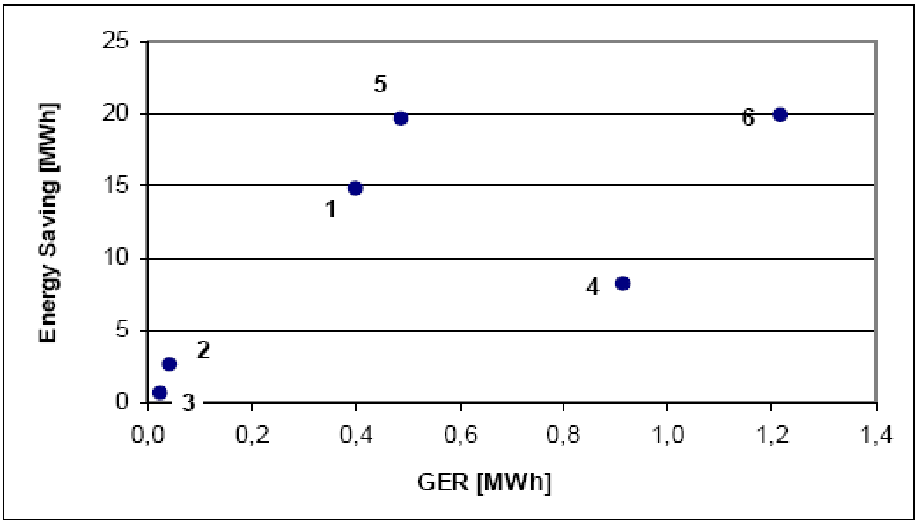


Figure 0-2 Comparison among GER and Energy saving

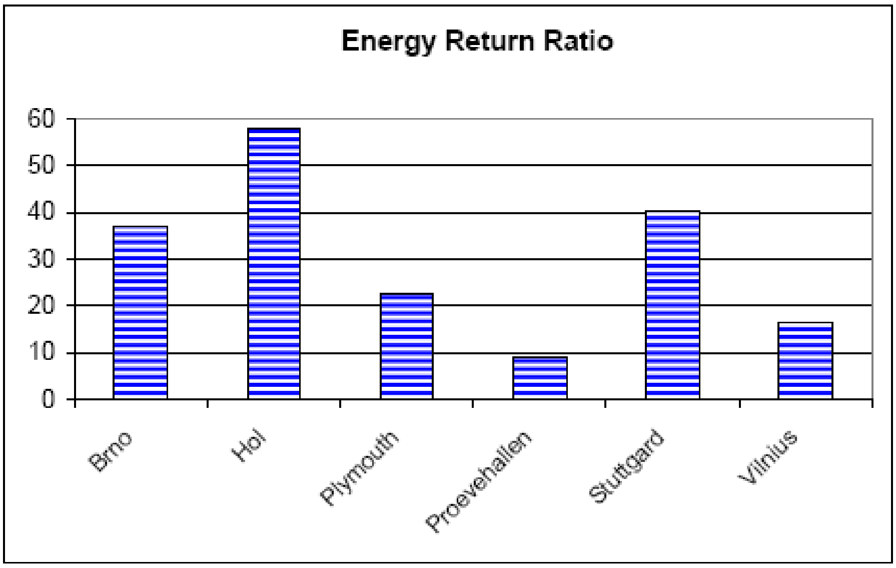


Figure 0-3 Energy Return Ratio Index

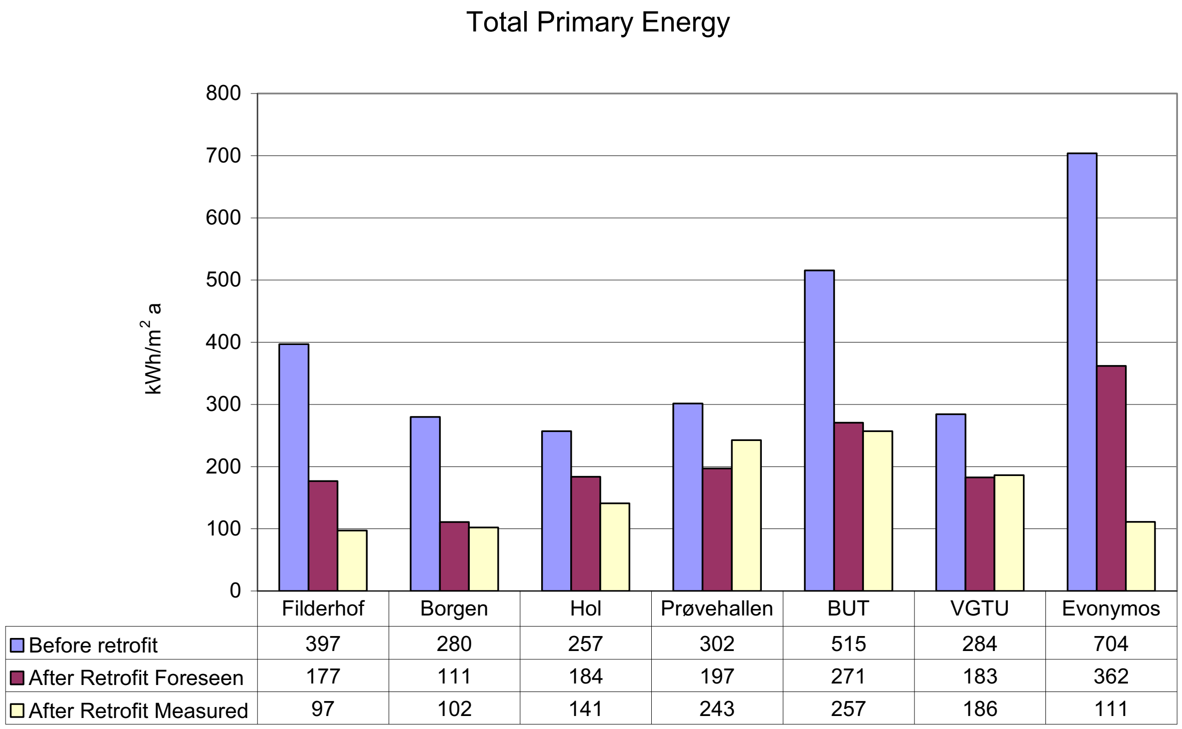
0.4.2 Energy

0.3.1.1 Primary energy

Following graph compares Total Primary Energy consumption before and after retrofit intervention. For sake of checking the accuracy of planning tools, the comparison between foreseen and observed data is included.

Results shows that in most cases the observed values are quite close to predicted ones: where they are significantly different (Filderhof and Hol), the predicted Primary Energy were higher than expected. In case of Prøvehallen the difference, as above mentioned, were inducted by unforeseen success of the building: the real user profile in this case was substantially different from what defined at the beginning of the project.

Evonymos presents a very high level of pre–retrofit Total Primary Energy. That is due to a very high value of estimated pre–retrofit electric energy consumption.

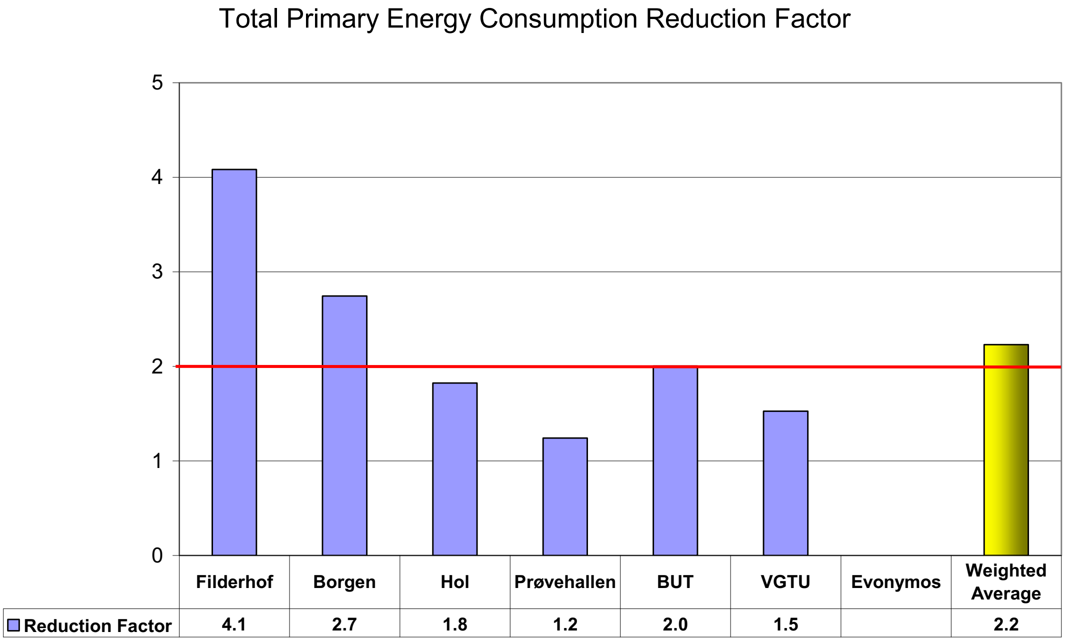

Total Primary Energy

	Filderhof	Borgen	Hol	Prøvehallen	BUT	VGTU	Evonymos
🟦 Before retrofit	397	280	257	302	515	284	704
🟪 After Retrofit Foreseen	177	111	184	197	271	183	362
🟨 After Retrofit Measured	97	102	141	243	257	186	111

The following graph represents the Total Primary Energy consumption Reduction Factor. Three of buildings are beyond the target requested by the project: Filderhof, Borgen and Brewery. One is very close to the target (Hol) and two (Prøvehallen and VGTU) are a bit farther. In case of VGTU the reason for the result seems to be the very high Primary Energy conversion factor (1,552) adopted for thermal energy and the lack of intervention for reducing electric energy consumption.

In order to provide an overall parameter that summarizes the result of the whole project, the average weighted Reduction Factor, where the weights are the floor surfaces of the buildings, was elaborated. The weighted average of Primary Energy Reduction Factor of BRITA in PuBs is 2.2: the whole project has then achieved the main required goal.

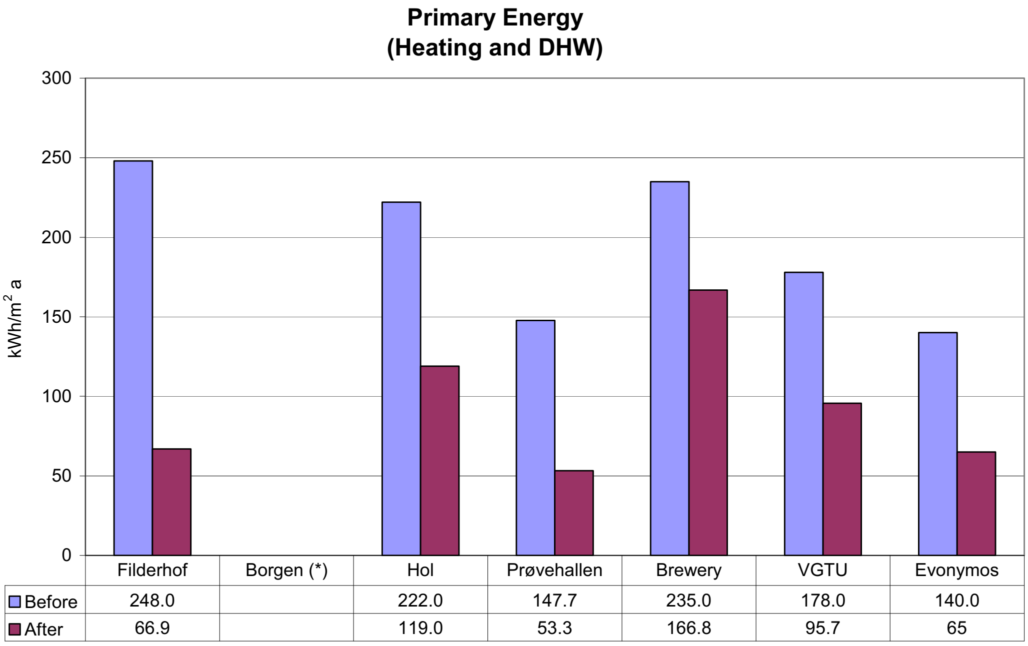
The result of Demonstration Building Evonymos is not reported in this graph because the very high value of Primary Energy Reduction Factor reported (6.3) was strongly affected by not reasonable values of before retrofit Energy Consumption.



	Filderhof	Borgen	Hol	Prøvehallen	BUT	VGTU	Evonymos	Weighted Average
🟦 Reduction Factor	**4.1**	**2.7**	**1.8**	**1.2**	**2.0**	**1.5**		**2.2**

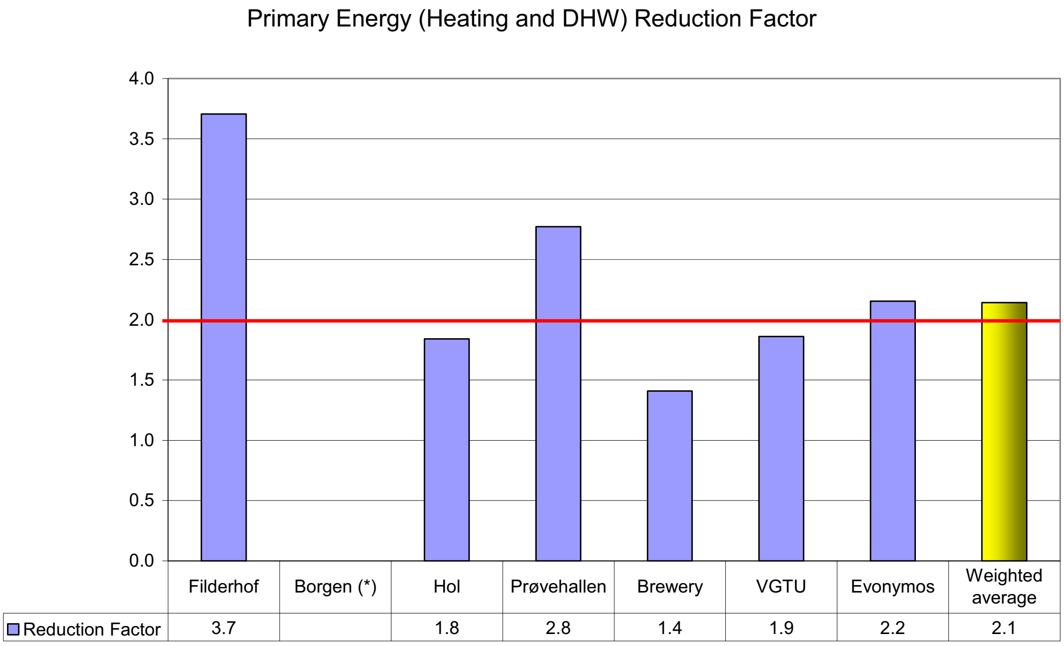
0.3.1.2 Heating

The following graph represents the comparison of Primary energy for heating before and after the retrofit intervention in all demonstration buildings. Data for Borgen are missing because the building uses electric energy for heating (as usual in Norway). Monitoring system does not distinguish between energy for heating system and other uses, so the results are reported only in the following data about Primary Energy for electric.



	Filderhof	Borgen (*)	Hol	Prøvehallen	Brewery	VGTU	Evonymos
🟦 Before	248.0		222.0	147.7	235.0	178.0	140.0
🟪 After	66.9		119.0	53.3	166.8	95.7	65

(*)Electric heat pump adopted: data for heating only not available

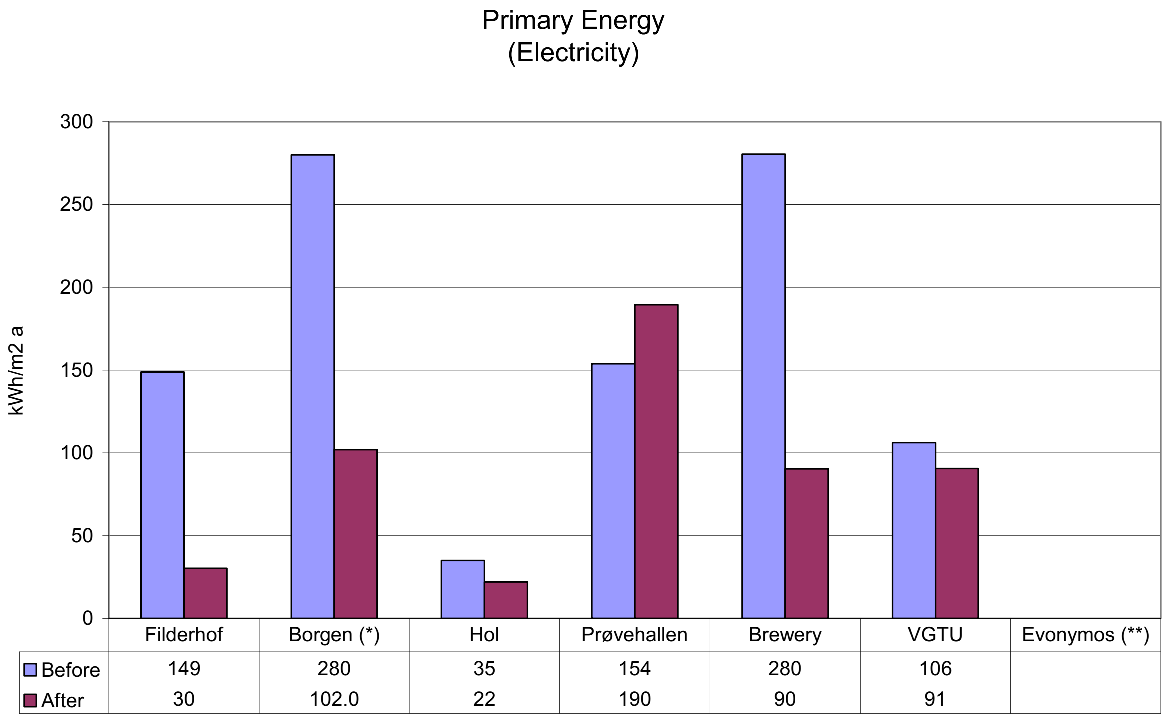

Primary Energy (Heating and DHW) Reduction Factor

	Filderhof	Borgen (*)	Hol	Prøvehallen	Brewery	VGTU	Evonymos	Weighted average
🟦 Reduction Factor	3.7		1.8	2.8	1.4	1.9	2.2	2.1

(*)Electric heat pump adopted: data for heating only not available
The overall result for PE is beyond the target: 2,1.

0.3.1.3 Electricity

Following graph represents the comparison between Primary Energy consumption before and after the retrofit intervention.

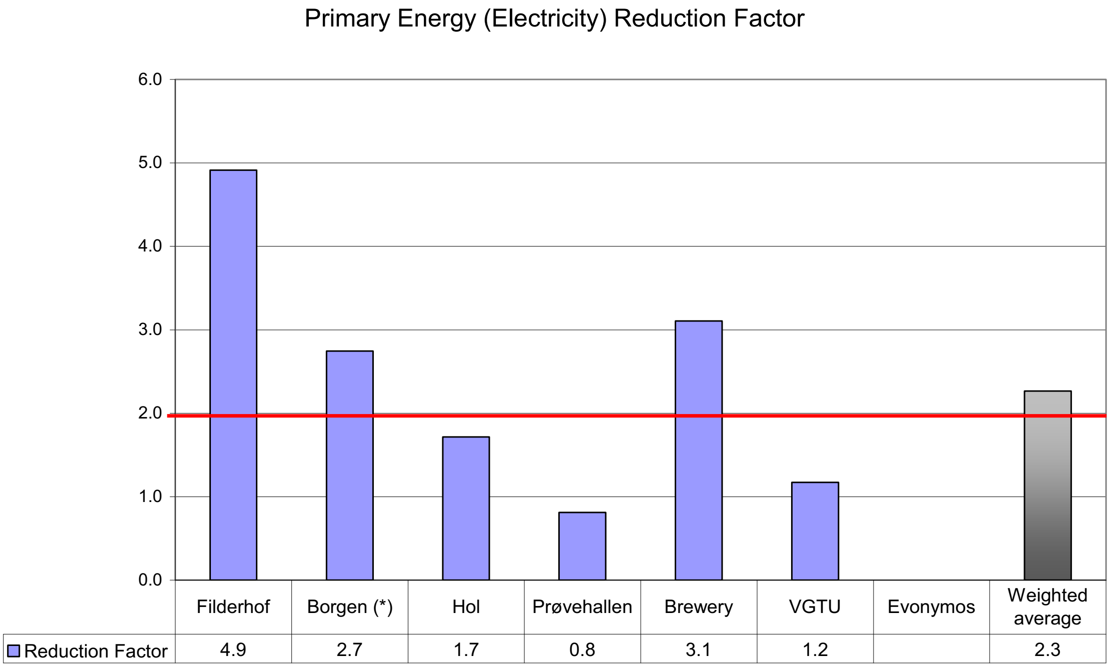

Primary Energy
(Electricity)

	Filderhof	Borgen (*)	Hol	Prøvehallen	Brewery	VGTU	Evonymos (**)
🟦 Before	149	280	35	154	280	106	
🟥 After	30	102.0	22	190	90	91	

(*) Electric Energy for heat pump included

(**) Not reported in this graph because not reasonable values of before retrofit Primary Energy (Electric) consumption were provided (561,8 kWh/m^2 a).

Results are quite different amongst Demonstration buildings: in case of Filderhof the combination of CHP and PV allowed to reduce the PE for electricity of about 80%. In Borgen the adoption of energy efficient lighting solution, daylighting strategies and geothermal heat pump allowed to reduce the energy primary energy of more than 60%.
The average of PE reduction factor is 2.3.

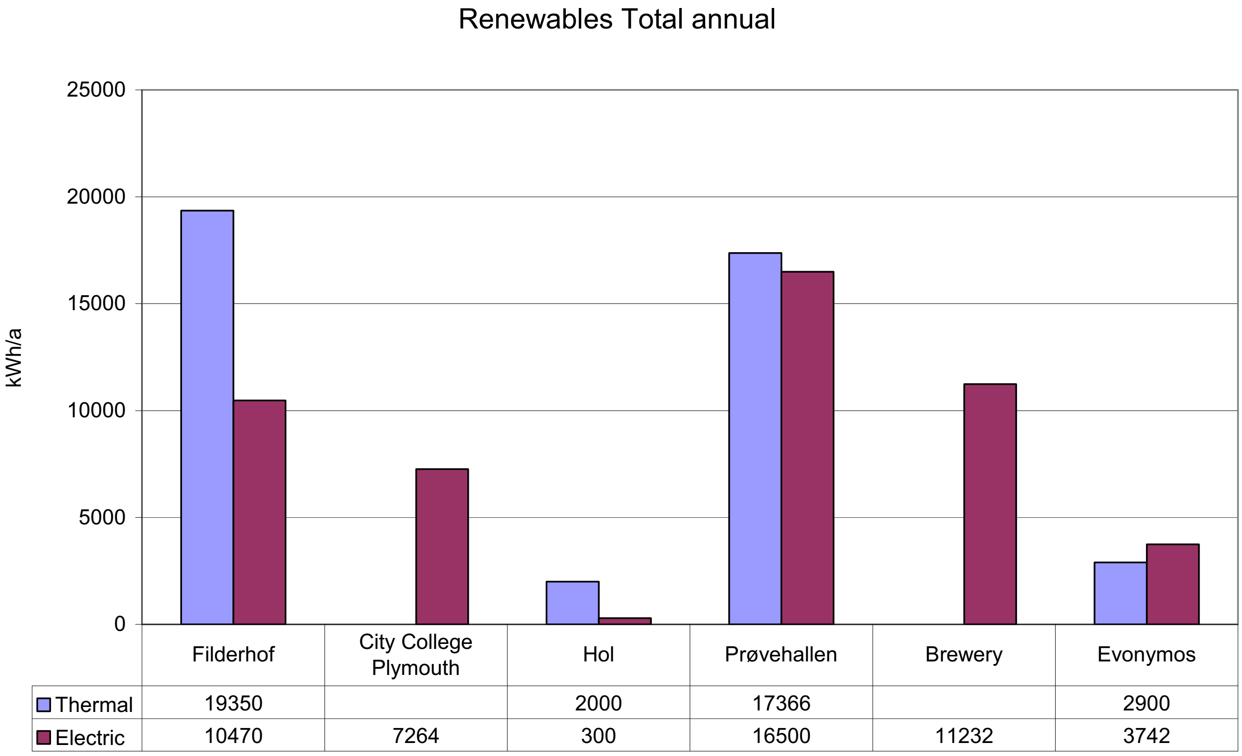


	Filderhof	Borgen (*)	Hol	Prøvehallen	Brewery	VGTU	Evonymos	Weighted average
☐ Reduction Factor	4.9	2.7	1.7	0.8	3.1	1.2		2.3

(*)Electric Energy for heat pump included

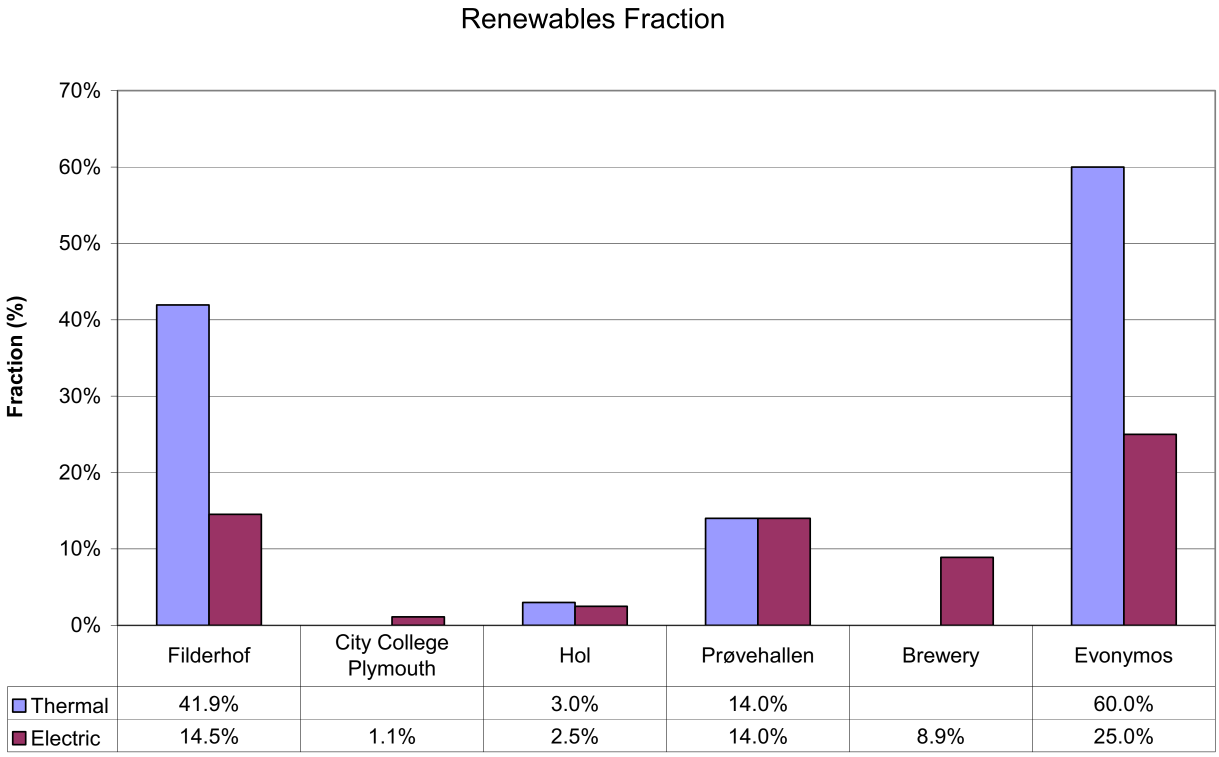
0.3.1.4 Renewables

Renewables were adopted by 6 buildings. Results are reported in following graphs.



Renewables Total annual

	Filderhof	City College Plymouth	Hol	Prøvehallen	Brewery	Evonymos
🟦 Thermal	19350		2000	17366		2900
🟪 Electric	10470	7264	300	16500	11232	3742



Renewables Fraction

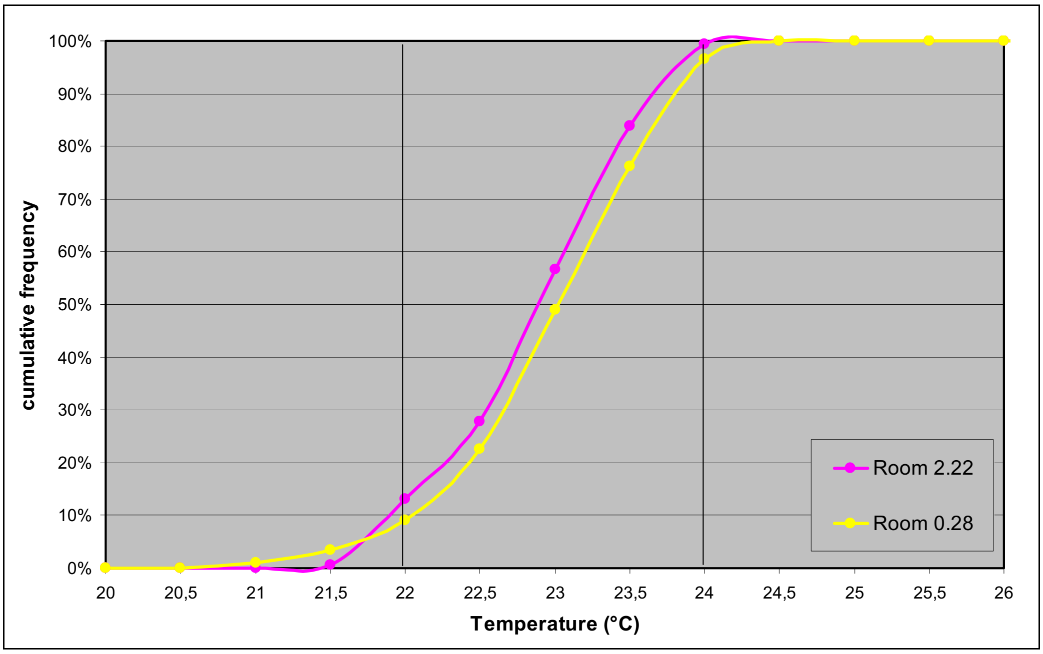
	Filderhof	City College Plymouth	Hol	Prøvehallen	Brewery	Evonymos
🟦 Thermal	41.9%		3.0%	14.0%		60.0%
🟪 Electric	14.5%	1.1%	2.5%	14.0%	8.9%	25.0%

Renewable fraction is very interesting in some cases (15% of electric from PV is definitely a good results for this kind of buildings), very good for thermal in case of Filderhof, definitely disappointing in case of wind energy in case of PCCollege. The reasons for that are very well documented in detailed report at chapter 2.

0.4.3 Comfort

All buildings reported an increasing of thermal comfort conditions, where a comparison was possible. Here some graphs that report the situation in some of buildings, in terms of absolute value (cumulative frequency curves) and in relative way (results of enquiries).

Filderhof:



Cumulative frequency curves of Air Temperature during the whole day.

Borgen:

“Over all the majority of the teachers was quite satisfied with the indoor climate and did not want any changes. There were other issues they were dissatisfied with, but they were more related to teaching facilities and teachers workspace.”

Hol:

An “overall user satisfaction survey” was carried out. It highlighted the comfort and energy issues through the following summing up question: -Have you noticed improvements in the indoor climate since last winter as regards draught, temperature etc.

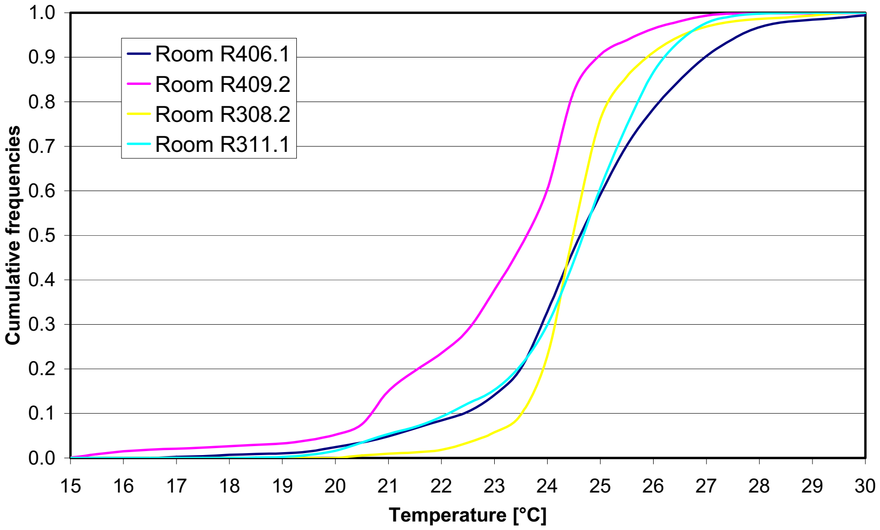
From the returned forms the following responses were drawn:

- Much better 55 %
- A little better 35 %
- No improvement 10 %

Prøvehallen:

	Percentage of time with 20<Ta<22 (Winter)	Percentage of time with 19<Ta<22 (Winter)
Drama room	100 %	100 %
Multiple hall	40 %	100 %
Foyer	70 %	100 %
Rhythmic	75 %	75 %
Big hall	100 %	100 %

Brewery:



Cumulative frequencies of temperatures in attic guest rooms

VGTU:
Gender specific surveys on indoor environment conditions:

Dissatisfaction percentage	After retrofit
	%
Male occupants	23
Female occupants	35
Total	29

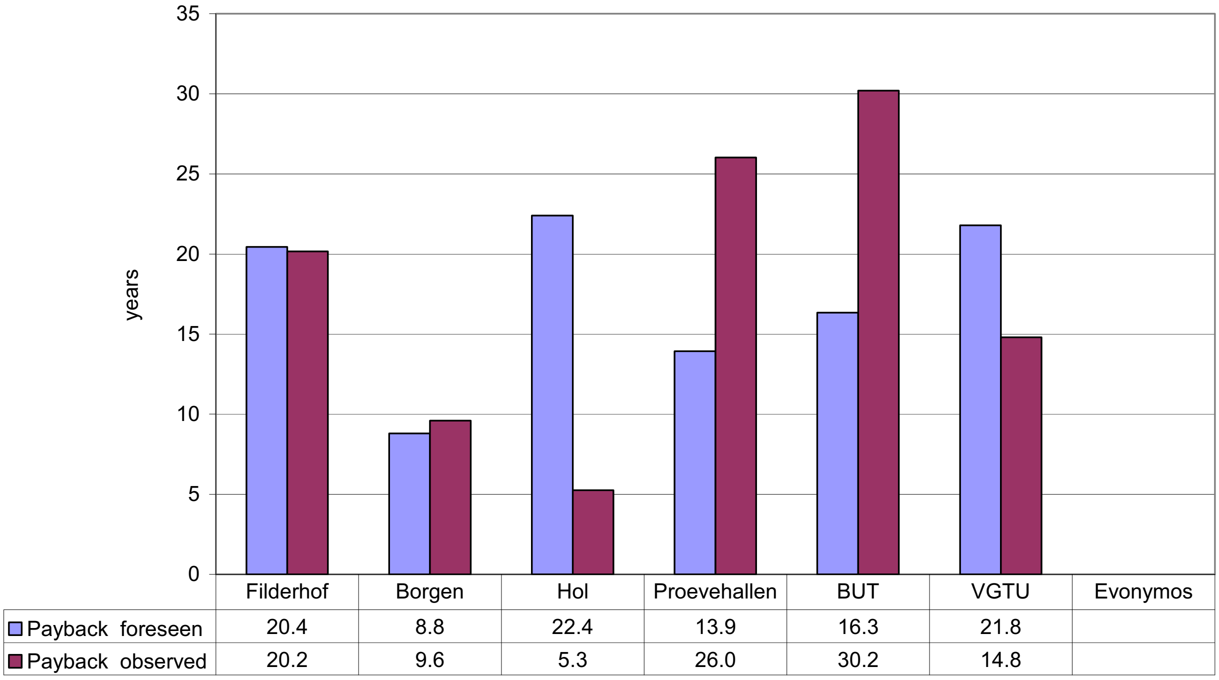
0.4.4 Economic evaluations

As above mentioned in the introduction paragraph, economic evaluation are a real issue in this field, due the strong and continuous increasing of energy prices. At the beginning of the project (2004) the oil price was around 30 $ per barrel, at the moment of writing these notes, the price is above 140 $ and some forecasts envisage it could increase to 200 before the end of the year. In this context to evaluate the payback period only could be a senseless exercise. Even the evaluation of NPV is really difficult in this situation: what kind of energy prices increase value should be adopted? Even the interests rate are increasing, and any forecast risks to be arbitrary. So, the payback value is reported only as a “photograph” of the past year (2007) situation.

It is anyway interesting to note how in some cases the observed payback period was substantially longer than expected, even in case of satisfying results from the point of view of energy efficiency, as above reported. This fact has to be evaluated carefully, but the first impression is that the buildings that present this kind of result are the same that had to face big problems for the realization of what foreseen at the beginning of the project and defined in planning phase (Filderhof and Brewery). Arising problems, during design (“Design is not a straight line..”) and construction phases force to find solutions that in most cases have a cost that is clearly represented in this graph. We could call it the extra cost of “uncertainty” of working on existing buildings. The third building with an appreciable increasing of payback period is Prøvehallen: in this case the problem is the above mentioned success of the building and the correlated use of building for more hours per days than expected.

Looking at these result we have the impression that if the imposed rules by the project would not be so stiff, these buildings would have given up some of the measures originally planned: to be forced to realise at any cost these measure produced this kind of result.

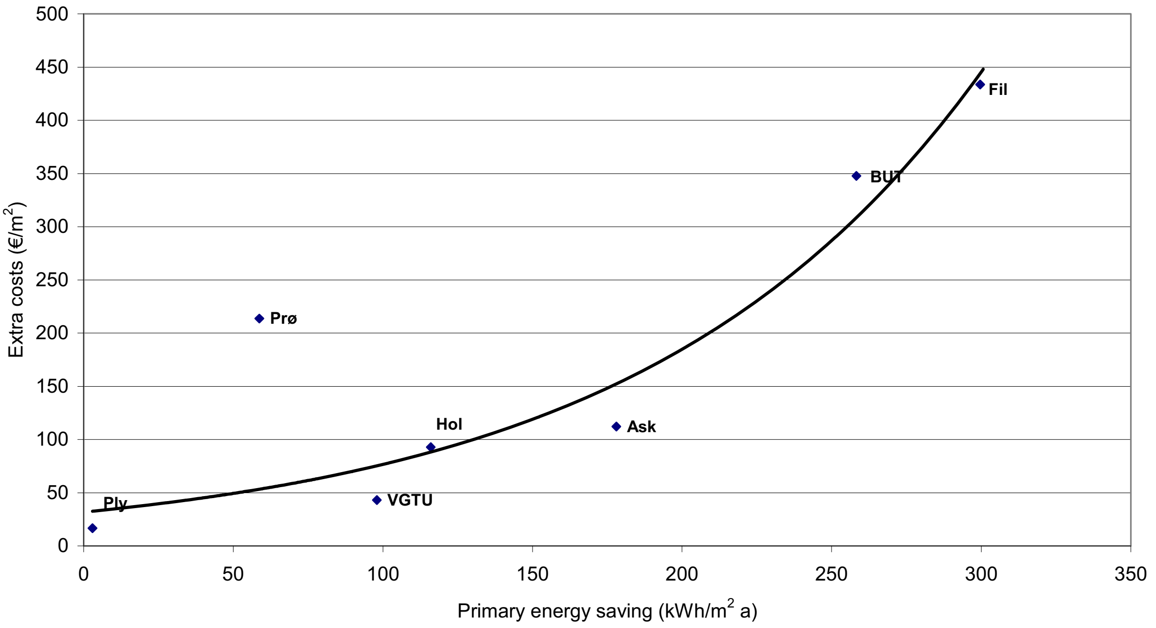
Payback period



	Filderhof	Borgen	Hol	Proevehallen	BUT	VGTU	Evonymos
🟦 Payback foreseen	20.4	8.8	22.4	13.9	16.3	21.8	
🟪 Payback observed	20.2	9.6	5.3	26.0	30.2	14.8	

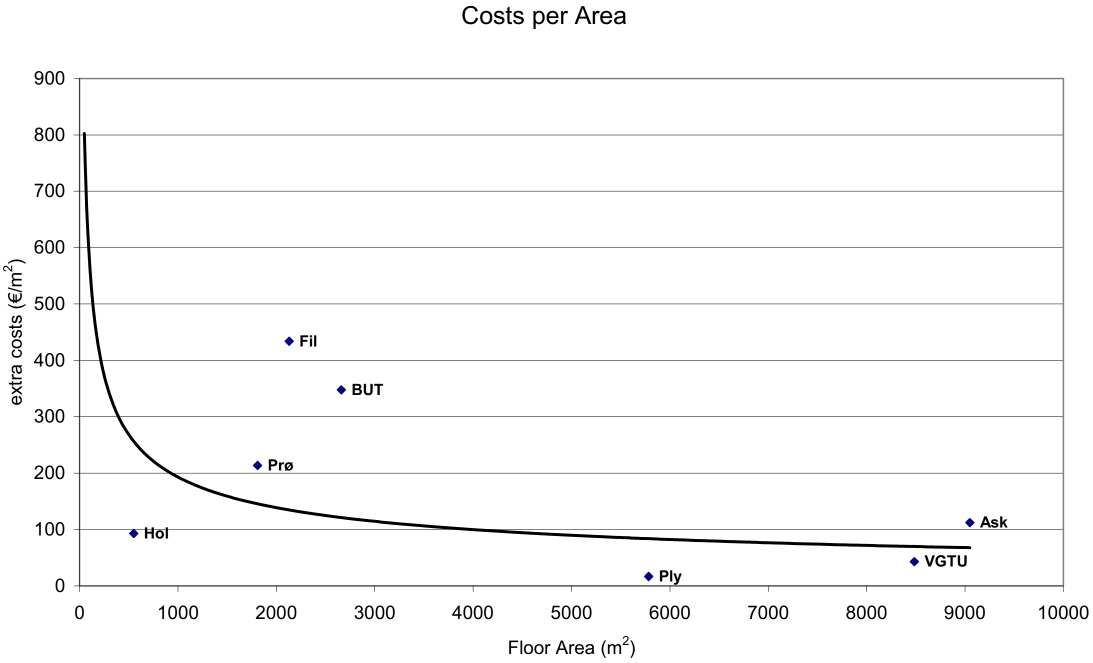
Other interesting economic evaluation can be done looking at observed extra costs in function of achieved energy saving (in terms of saved kWh/m^2 a). We called it "the cost of efficiency". Here the graph.

Cost of Efficiency

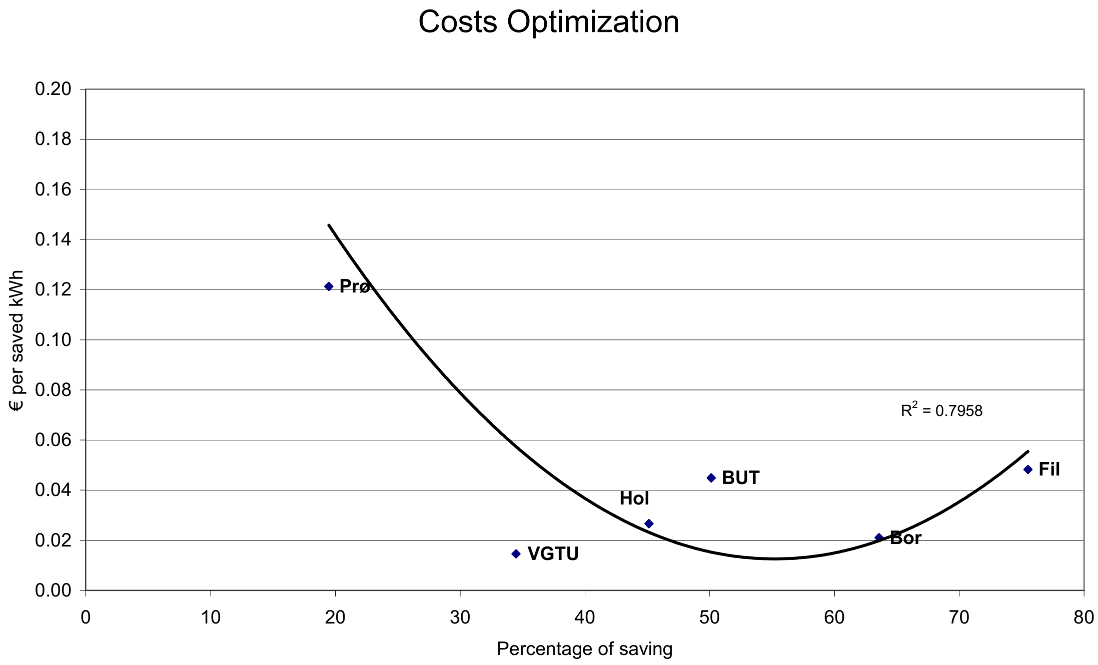


Almost all buildings present values that are on the regression curve. Prøvehallen is a bit higher for the mentioned reason of electric energy consumption that are reported much higher than expected due to an extra use of the building as theatre.

Another interesting parameter is the extra costs in function of building size. Here the figure:



In this figure, again, the three buildings with problems of realizing what promised, are above the regression curve, and two of them are quite far away.
Finally, trying to find the optimum of energy saving, this diagram has been constructed.



Looking at cost per saved kWh (where that cost was calculated with a measures lifetime of 30 years), it seems that optimum, for these buildings, is to save around 50% of energy. That was, by the way, the target of the project…

As already above mentioned, these graphs do not include results from Evonymos due the uncertainties about the pre-retrofit values of energy consumption.

0.5 Lessons learned

Here a selection of the most interesting lessons learned reported by Demonstration Partners.

0.5.1 Filderhof

Architectural aspects (influences) may have a strong influence into the retrofit concept even if a building is not listed

Economic influences may change the material used for building parts

The planning process over five years requires changes in the retrofit measures of a building.

It is necessary that the operation staffs are trained in energy efficiency.

There is a lot of coordination work to be done with several partners of the project inside the city and especially with financial government.

0.5.2 Plymouth City College

Wind turbines planning:

The most important issue, for those considering a wind turbine is to do a year of wind speed monitoring before making the decision to purchase. DO NOT rely on existing wind speed data bases.

Installation:

It is essential that a local installer is used who takes full legal responsibility for the units they supply. The installer must be instructed to fully consider all design issues before starting work. An installer with proper experience of installing wind turbines is essential.

Comfort related issues:

The effects of shadow flicker must not be underestimated

Vibration is a issue. To erect turbines on existing building the original structure design must be available

In windy weather the noise from the turbines is more significant because the turbine is running more Fast. The sound can be experienced directly underneath the turbines adjacent to the building.

0.5.3 Borgen

BEMS system has helped to optimize operation of technical installations and put focus on energy consumption.

Problems with sound carried from one room to another through ventilation culverts. Measures had to be taken to minimize the problem.

Building underground culverts along existing constructions is difficult, time consuming and expensive.

Moisture from rain and snow enters the system from the inlet towers and caused the lower part of the wall enclosing the filter unit to become moist.

The sophisticated BEMS system requires skilled operators and a long testing and adjustment period.

Technical personnel should be educated during the building period to get acquainted with the technical installations before the building is opened.

0.5.4 Hol

The important job of Antiquarian Authorities (protecting the valuable listed buildings) often is in conflict with the equally important job of reducing the energy need in existing buildings.

A motivated client and a motivated caretaker is a crucial element towards success.

0.5.5 Prøvehallen

To be careful in estimating the energy consumption is really important, but when uncertainties of these assessments are high, a careful plans of monitoring of the energy consumptions of energy uses has to be foreseen. The heating energy consumption and savings were correctly estimated - they are much less sensitive to the use of the building.

As always the first reaction from the contractors is that "this is too expensive". In the actual situation it was the BEMS system. But by negotiations it finally got through the process.

Many people has visited Prøvehallen and has with great interest learned about the energy saving measures and the renewable energy systems.

0.5.6 Brewery

Design phase proved the saying that "design is not a straight line". Many changes had to be made in the proposed energy-saving measures.

Be open-minded and ready for changes. The design phase is virtually not over until the building is "fully" operational. Do not try to be innovative at all costs. A "traditional" solution that works is much better than an innovative one that does not (and can even have higher "replicability").

Commissioning means much more than handing over the building to the investor. Good contractors know that very well, therefore, avoid signing a contract with the other ones.

Do not underestimate the importance of educating the building users.

0.5.7 VGTU

Because of the financial shortages the attention was not paid to. ventilation and in consequence the ventilation system was not foreseen to be refurbished.

In the renovation process economical reasons have lead to the development of the project modification. This has been done in close cooperation with the builder and VGTU authorities. Ventilation system renovation becomes a must when you act on envelope airtightness.

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[a] MCitterio et al. "Brita in Pubs D8 - Reports on the concept development of the demonstration buildings in BRITA in PuBs" October 2005

[b] MBeccali, MCellura, FArdente "Life Cycle Assessment (LCA) of the BRITA demo building retrofits - Analysis of the environmental benefits and burdens related to demo-building retrofit actions" June 2008

1 Filderhof, nursing home

Authors: Dr. Jürgen Görres / Nina Weiß / Sandra Langer

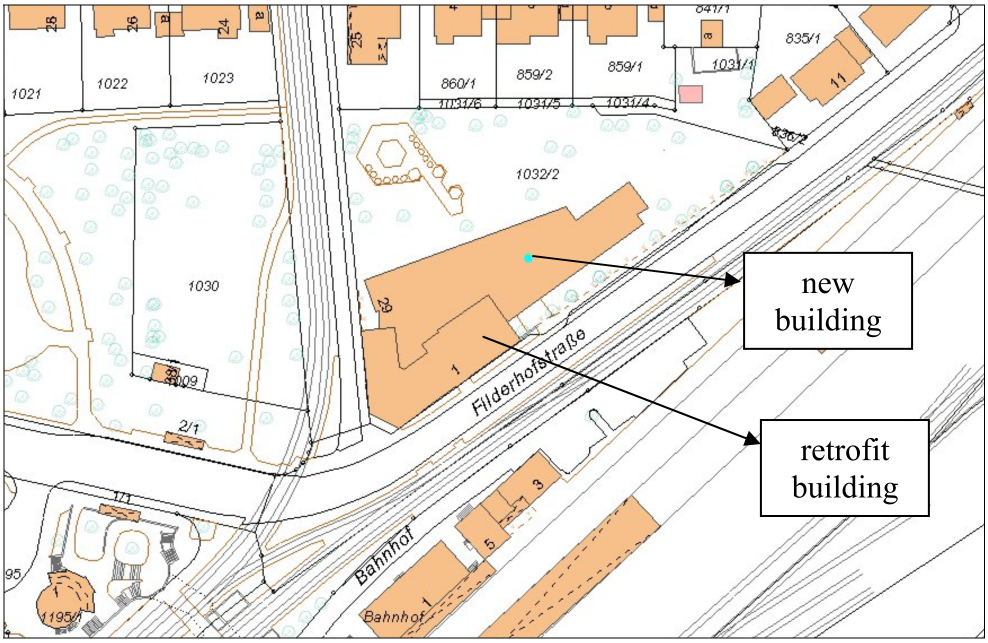
1.1 General data

1.1.1 General information

Year of construction:	1890, with an extension from 1952
Year of renovation (start):	2005
Number of levels:	4
Heated volume (m³):	-
Cubic contents, volume (m³):	8964
Gross area (m²):	2131, before retrofit the gross area was 2875 m²
Living area (m²):	-
Floor area (space) (m²):	2131
Window / glass areas (m^2):	161 / 142

1.1.2 Site

The Filderhof is located in an urban surrounding in the south of Stuttgart. On the south side of the building there is the local railway station '(Stuttgart-) Vaihingen'. On the west, the north and the east side a small park/garden surrounds the site.
Address of the demo building: Filderhof, Herrenberger Str. 29, 70563 Stuttgart



Building site of the Filderhof in Stuttgart

Stuttgart is a city in the southwest of Germany. The geographic position of the site is: Longitude 9.2 E, Latitude 48.7 N. The altitude of the district of Vaihingen is 420 m above sea level. The lowest winter temperature in 2004 was -10 °C, the highest summer temperature 36.8 °C.

Location of the demo building Filderhof in Germany.

The average annual temperature is 8.6 °C, the average winter temperature is 5.8 °C. Generally the lowest temperature in winter can drop to –24 °C. The norm degree days in Stuttgart are 3555. In 2004 there were 3386 degree days. For the Test Reference Year (TRY) the city "Würzburg" is the baseline.

1.1.3 Building type

The Filderhof was built as a classy hotel in 1890. After the Second World War the building was used as a hospital and got an extension in 1952. Since 1979 it's a nursing home for elderly people and people with dementia. Therefore it fits in two typologies: accommodation and social facility. In the recent phase of construction, the building was totally renovated and enlarged by an extension.

1.2 Before retrofit

1.2.1 Building construction

The external walls of the Filderhof are made of different materials. Partially bricks are used and partially natural stones with mortar. Furthermore, the wall thickness ranges between 24 cm and 40 cm. So the external walls differed in most of the rooms. According to the year of construction, the building had no insulation: the walls, the roof, the upper ceiling and the cellar ceiling weren't insulated. Though the old windows had double glasses, they had a bad u-value and an insufficient noise protection against the passing train.

The U-values before retrofit are assumed in the following table.

	U-value [W/m²K]
windows	3.0
Walls	1.4
Roof	1.0
upper ceiling	2.0
cellar ceiling	1.9

A total renovation and an enlargement of the building were necessary. Since the energy consumption of the building was very high in comparison to the public building stock of Stuttgart, the city decided to realize also an energy retrofit.
The exterior facade has many historical elements, which are worth to be kept. For instance the balcony, the frame of the entrance door and the architrave block of the building. Therefore an external insulation couldn't be realized.

The photos below show the state of the building before retrofit.

South-East facade of the Filderhof

South-West view of the Filderhof

Old main entrance

Upper ceiling

1.2.2 Existing heating, ventilation, cooling, lighting systems

The heating system was installed in 1952, though the boiler with a thermal heat power of 276 kW was replaced in 1988. The efficiency of the furnace was only at 88 % and the heating system had an old control system. The preheated water flowed with 80 °C to the radiators.

Existing boiler.

Old heat distributor

The boiler system didn't work very efficient because of the loose-hanging insulation and the missing of any measuring and control system. Furthermore the old heating pipes were all in the external wall, largely without any insulation, why the system had a lot of distribution losses

Existing ventilation and cooling system
No mechanical ventilation system was installed. The building was ventilated solely by the windows. A cooling system in this residential-like type of building isn't necessary in Germany.

Existing lighting system
The lighting system consisted of energy saving fluorescent tubes and bulbs in the rooms and the traffic areas. It was controlled by manual switch on/off. The lighting system didn't work very efficiently and the power of the installed lighting system ran up to 12.5 W/m² for 300 lx.

The old lighting system

1.2.3 Energy and water use

	Measured year (2001)	Total for the whole building
Space heating	227 (248*) kWh/m^2 a	652 974 kWh/a
DHW	above included	above included
Electricity	40.8 kWh/m^2a	117 157 kWh/a
Water	2 050 l/m^2a	5 889 m³/a

*weather adjusted (by using degree days)

	Measured year (2004)	Total for the whole building
Space heating	249.9 kWh/m^2 a	679 468 kWh/a
DHW	above included	above included
Electricity	45.5 kWh/m^2a	131 134 kWh/a
Water	1 794 l/m^2a	5 213 m³/a

1.2.4 User satisfaction before retrofit

An interview with 10 persons was done to find out the user's attitude of Filderhof before retrofit. The users are residents and employees (nursing staff and office staff).

All users approved of the temperature in wintertime, however there were different opinions in summertime. 80 % of the staff felt too warm in summertime, but only 40 % of the residents. Most of the residents (60 %) accepted the temperature in summertime. The residents fully accepted the air quality (100 %) and so did a 70 % - majority of the staff. The odour of the stock did hardly become conscious to anyone. The odour mix of food and persons etc. was unsurprisingly more recognized by the staff as by the residents. (80 % of the residents did not recognize it at all, the staff judged it as a usual smell).

Very informative results were delivered by the questions about the ventilation behaviour. In average over a 24 hours period 80 % of the residents declared they always had their windows open (16 % wide open, 64 % tilted). That was the case at only 36 % of the staff (4 % wide open, 32 % tilted). Depending on certain situations the windows are opened mostly after nursing (70 % open), followed by the time after lunch or dinner (50 % open). After nursing the windows will be tilted at 50 %, which means that it will stay tilted for a while. Only 20 % of the persons open their window widely for a quick and complete air exchange. After lunch or dinner the window will be opened widely at 30 %, and it will be tilted at 20 %.

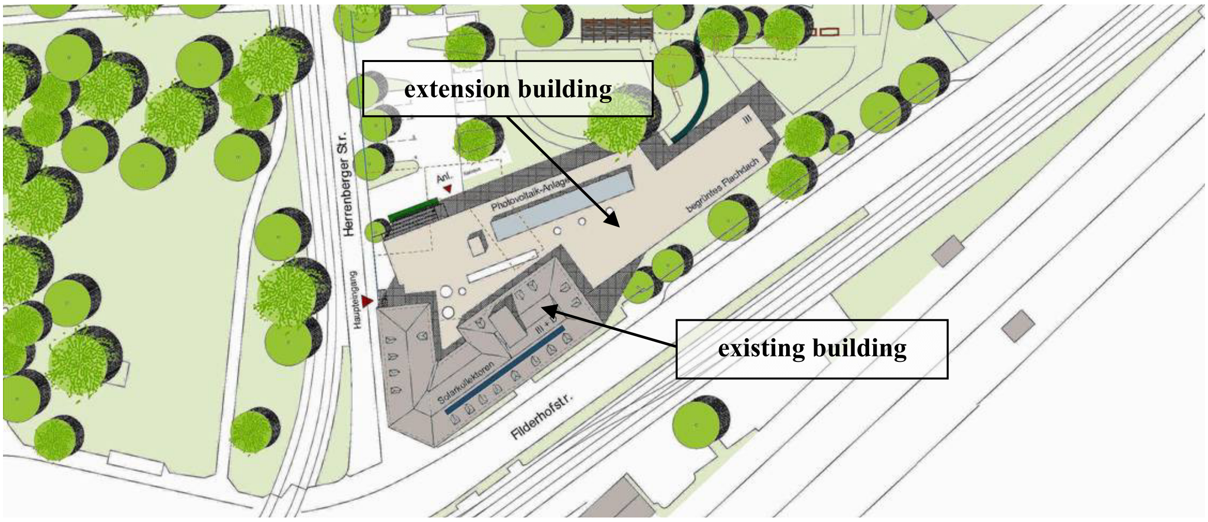
When the residents were asked who would open the windows, 40 % of them answered the staff would do it. 60 % of the residents opened the windows themselves. There was a big difference between residents and staff about their sensation of the draught. 70 % of the staff but no resident assessed the closed windows as draughty. The air quality in the common area was pleasant for all residents, but only 50 % of the staff found it acceptable.

The imagination of having a shower and a toilet in their own room after refurbishment was pleasing for 90 % of the interviewed. All users agreed with the brightness of the rooms and the size of the windows was quite right at 70 %. Therefore the residents declared to use electrical light only for 1-2 hours a day (80 %), whereas the staff uses electrical light for 3 hours a day in average. The corridors were too dark for all of the staff but for all of the residents they were well illuminated. The lounge was too hot for most of the users in summertime (70 %). The tram passing by was very thunderous for 70 % of the interviewed.

One staff-member issued: “The nursing home was not up to date, it was very old. The two bed rooms were much too small, people could hardly move, the shower and the bathroom was not satisfactory for the number of residents. For those confined to bed, the distance between their rooms and the bathroom was too long and they had to use a lift. The shutters were mostly not functioning; as a result it was not possible to dim the rooms. The staircase was inadequately passable for the residents, when one window was open; there was a draught on all floors.”
An other staff member said: “The rooms were too small as a two bed room. The corridor was too narrow and to dim.”

1.3 Energy saving concept

A renovation of the entire building, including the technical systems was necessary. The windows were changed, the walls insulated, a new heating system with solar plant and a combined heat and power unit was installed. The lighting system was completely rebuilt and a PV-plant was erected. At the back side of the existing building an extension was erected. The two buildings are connected with an atrium.



Existing building and the extension building

The planning process of the energy retrofit measures started in 2004. The construction phase started in the end of 2005 and was finished in May 2007. The monitoring period started in April 2007.

1.3.1 Building construction

All the windows and entrance doors were retrofitted. The new windows have high efficient triple-glasses with a u-value of 1,0 W/m²K and thermal spacers to minimize the thermal bridges at the edges. Furthermore they have a high noise protection against the passing train.

Originally it was the intention to insulate the external walls from the outside with a composite insulation system (polystyrene insulation covered with plaster). But in order to keep the architectural expression of the building (frame of the entrance door, balcony, stone plinth of the building), there was the decision made for an internal insulation on most parts of the old building. This had the consequences that a lot of technical details had to be solved in order to prevent thermal bridges. Furthermore there was an intensive controlling of the installation of the vapour barrier necessary. Only about 20 % of the old building got an external wall insulation.
To reduce the heat losses over the roof a 14 cm thick thermal insulation was fixed between the rafters. Additionally 5 cm thick insulation was fixed below the rafters. The upper ceiling of the building was insulated with 16 cm mineral fibre between the beams and insulation plates with 5 cm thickness were laid on top of the ceiling.

The use of some basement rooms changed, so they'll be heated now. Thus the thermal insulation had to be modified as well. The heated areas, which are used as kitchen and as dressing room, got insulation on the base floor (foamglass) and on the inside of the walls. In the other cellar rooms the ceiling is insulated.

	Pre retrofit U-value [w/m^2]	Post retrofit U-value [w/m^2]
Walls	1.4	0.2
Roof	1.0	0.2
Windows	3.0	1.0
Doors	-	-

1.3.2 Heating

The old heating system was completely replaced. The new heating plant consists of two gas condensing boilers, a combined heat and power unit and a thermal solar plant. The new system temperature of the radiators is 60°C flow and 40°C return flow. The two gas condensing boilers have a thermal power of 150 kW each and the combined heat and power unit has a thermal power of 32 kW and an electrical power of 17 kW. The old heating pipes were completely replaced by new ones.

1.3.3 Ventilation

To transport the humidity away from the new bathrooms and to ventilate the kitchen rooms, two independent ventilation systems were installed. One ventilation system vents the kitchen rooms with up to 4500 m³/h and the other plant exhausts the care bathrooms and restrooms in the old building with an air flow rate of 5500 m³/h. The air inlets of these systems are located in the corridors. Via the doors, the air gets into the rooms and the humid air in the bathrooms will leave the building. In order to reduce the ventilation losses the system will have a heat recovery rate of over 80 % for each ventilation systems. All the other rooms will be ventilated by opening the windows.

1.3.4 Solar Thermal & Solar PV

Further more a thermal solar plant is realized for domestic hot water. The plant consists of 25 collectors, which are installed on the south east and the west side of the roof of the old building with an inclination of 45°. The collectors have a surface of 60 m² and can provide thereby 32 % of the domestic hot water demand.

A photovoltaic system with a surface of 105 m² is installed. The maximum power of the plant amounts to 12.6 kWp and the 90 monocrystalline modules produce 12615 kWh (in advance calculated) per year. This means a reduction of the greenhouse gas CO_2 of around 8.7 Tons per year.

View from south-east: Old building with solar thermal system, new building with photovoltaic


Thermal solar plant


Photovoltaic System

1.3.5 Lighting systems

To reduce the electricity consumption the daylight use is improved and the nursing home got an energy efficient lighting system. The new atrium, which connects the old building with the new building, gets natural daylight via roof skylights


Roof skylights in the atrium


Roof skylights

Instead of mechanical ballast, all lamps will get electrical ballast. In the near of the windows the lamps will be controlled in dependence of the daylight. The installed electrical power of the lighting system was reduced to 2.5 W/m² per 100 lx. The new motor of the elevator saves around 40 % of the electric energy consumption and the heating plant got energy efficient circulation pumps.

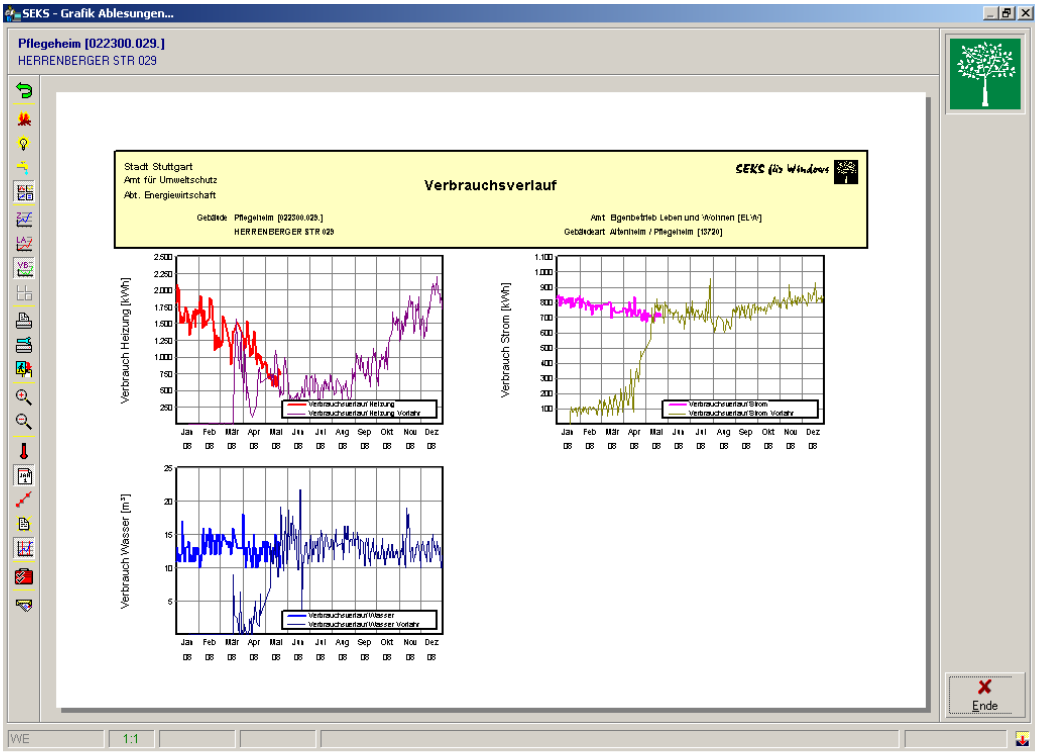
1.3.6 CHP

A combined heat and power unit with an electrical power of 17 kW and a thermal power of 32 kW was installed. For the combined heat and power plant the domestic hot water consumption was measured. The CHP – plant was planned according to the thermal heat requirements and the power gained by the thermal solar-system as well as the electrical power consumption of the building. The CHP works cost-effectively with a high number of working hours. Thus the electrical power was reduced to 18 kW.

1.3.7 BEMS

The Building Energy Management System (BEMS) consists of two elements. First a conventional control system (saia control) is installed in the building. It adjusts the water temperature of the heating system depending on the outdoor temperature. In dependence of the heat consumption, the control system has to decide, from which energy source the heat has to be produced: from the combined heat and power unit, from the condensing boilers, from the solar plant or from the storage tank. Finally the BEMS has to determine, when the storage tank will be reloaded and when the combined heat and power unit has to reduce its power supply.

Additionally the Stuttgart's Energy Control Management (SEKS is used to control the daily energy consumption of the building. With this system, the energy managers in the office for environmental protection are informed automatically about the energy consumption of the building. The energy values are transferred over the telephone network. Specially developed software visualizes the energy values into a PC. Thus a long-term controlling instrument is installed. The photo below shows the visualisation of the energy values with the SEKS.



Pflegeheim [022300.029.]
HERRENBERGER STR 029

Stadt Stuttgart
Amt für Umweltschutz
Abt. Energiewirtschaft

Verbrauchsverlauf

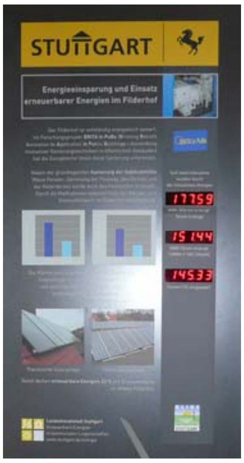
Gebäude Pflegeheim [022300.029.]
HERRENBERGER STR 029

Amt Eigenbetrieb Leben und Wohnen [ELW]
Gebäudeart Altenheim / Pflegeheim [13720]

Screenshot of the developing of energy values

The innovative elements of the nursing home are presented to the public by an information panel in the atria. The energy which is produced by the CHP, the PV and the solar thermal system is therefore automatically transferred to this panel. Additionally the CO_2 Reduction by these systems is calculated

Presentation of the information panel



information panel

1.3.8 Predicted energy savings

Energy saving measures, heating, cooling, ventilation	[kWh/m²a]	Total [kWh/a]
High efficient windows	20	42 600
Insulation of the opaque elements	79	167 400
Ventilation	39	82 500
Heating system	45	95 900
Solar heating system	11	23 400
Total heating energy savings	**194**	**411 800**

Energy saving measures, electricity	[kWh/m²a]	Total [kWh/a]
Heating system (CHP)	37	78 800
Efficient lighting	10	21 300
Daylighting transfer	3	6 400
PV-system	6	13 700
Total electricity energy savings	**56**	**120 200**

1.3.9 Predicted costs and payback

Energy saving measure/investment	Area [m²]	Total costs [EUR]	Eligible costs [EUR]	Saving [EUR/a]	Pay-back periods [a]
high efficient windows	260	82 800	82 800	1 900	43.6
insulation (wall, roof, basement)	2 002	246 700	228 400	7 400	30.9
Ventilation	2131	99 800	67 800	3 600	18.8
heating system	2131	279 100	176 900	15 000	11.8
solar thermal DHW	60	30 000	30 000	1 000	30.0
efficient lighting	2131	213 000	85 200	2 900	29.4
day lighting transfer		20 000	20 000	900	22.2
PV-integration	105	98 000	98 000	5 900	14.0
Total		**1 069 400**	**789 100**	**38 600**	**20.4**

Energy costs used for the payback calculation (2004):
Thermal: 44 €/MWh
Electric: 137 €/MWh
Fictitious input into the grid: 514 €/MWh

1.4 Life Cycle Assessment

Primary energy saving and emissions			
Primary energy save (E_{year})	19 706 473.0		[kWh]
Global Emission saving (EM_{S-i})	2 293.2		[ton$_{CO2\ eq.}$]

Summary of materials employed and main components			
Component			
Mineral wool	14.1		[ton]
Polystyrene	0.73		[ton]
Glass wool	0.25		[ton]
Wood wool	0.25		[ton]
Concrete	40.0		[ton]
Bricks	1.0		[ton]
Steel	5.0		[ton]
Wood	2.0		[ton]
E-saving lamps (power)	47.5		[kW]
High efficient windows	139.1		[m^2]
Monocrystalline PV plant	105.0		[m^2]
Combined heat and power unit	32.0		[kW]
Thermal solar plant	60.0		[m^2]
Condensing boilers	320.0		[kW]
Radiators and pipes (steel)	12.2		[ton]

Energy and Environmental Indexes			
Global Energy Requirements (GER)	486 983.0		[kWh]
Global Warming Potential (GWP)	100.6		[ton $CO_{2-Eq.}$]
Nutrification Potential (NP)	45.9		[kg PO_4]
Acidification Potential (AP)	629.4		[kg SO_2]
Ozone Depletion Potential (ODP)	0.04		[kg CFC_{11}]
Photochemical Ozone Creation Potential (POCP)	105.0		[kg C_2H_4]

Synthesis Indexes			
Energy Payback Time (E_{-PT})	0.33		[year]
Emission Payback Time (EM_{-PT})	0.34		[year]
Energy Return Ratio (E_R)	40.5		

1.5 Construction phase description

1.5.1 Building construction

In order to retrofit the whole building it was completely dismantled. All windows were replaced with high efficient triple-glass windows. The covers of the ceiling, the floor and the walls were completely removed.

Retrofit of the roof

interior view during construction

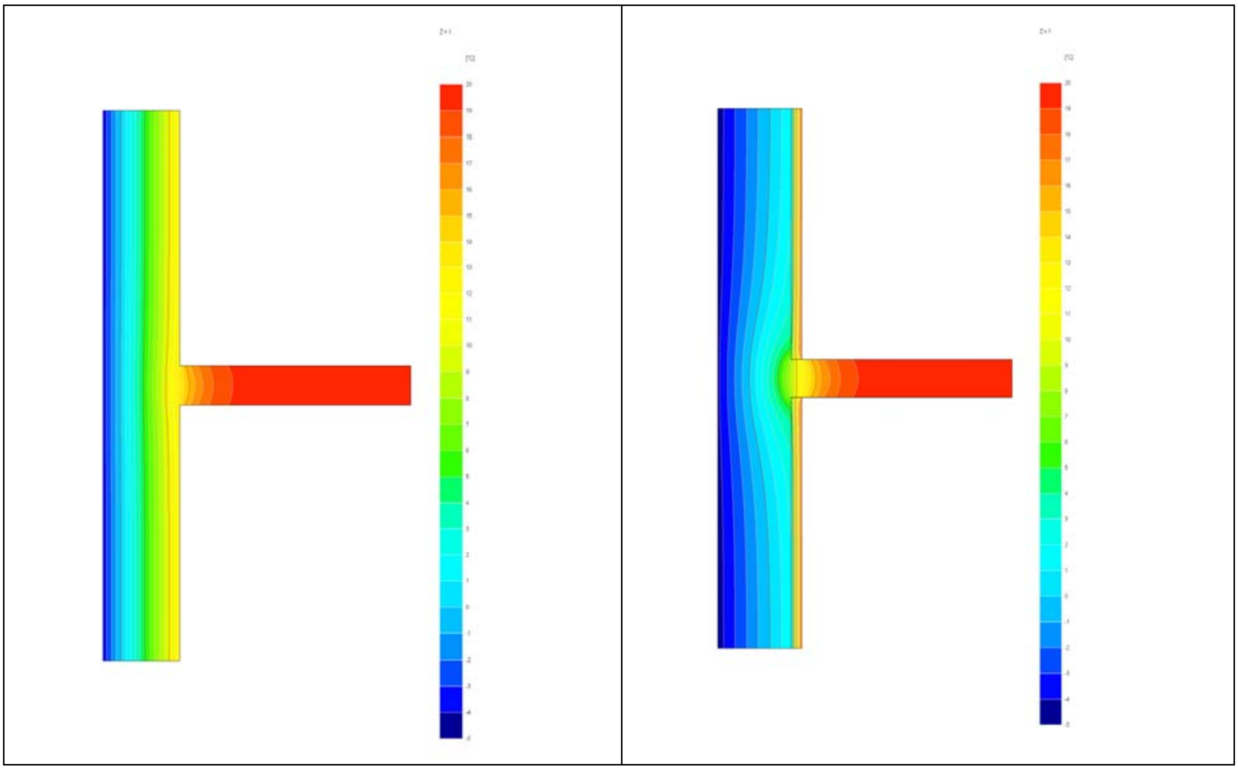
During the planning process ways to apply vacuum insulation were investigated. Unfortunately the vacuum insulation could not be applied in the project, because the system wasn't suitable for our building. The vacuum panels need an absolutely planar surface as a basic requirement for a technically flawless installation. As the walls are very uneven, the effort to achieve this demand would be extremely high and connection points as reveals couldn't be done at all with the vacuum panels. Furthermore the long term behaviour of these systems is still uncertain and there's also the risk that the panels get hurt during installation, as well as in daily use of the building.

Next the engineer team wanted to take a mineral insulation board (multipor), but the surface wasn't even planar enough to stick these boards. Therefore the team decided to take mineral-fibre wool with different thicknesses and an individual construction frame (aluminium profile frame planked with sheetrock). The internal insulation with the aluminium profile frame was masked with a vapour barrier. For this a high quality control was necessary because humidity must not infiltrate.

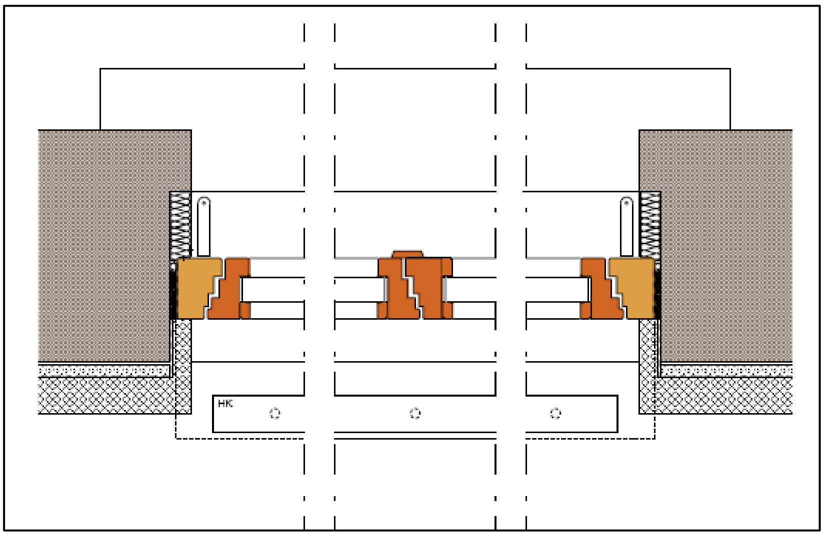
Aluminium frame for the insulation

Internal insulation with vapour barrier

By a finite element calculation the temperatures in the wall are quantified to determine the thickness of the insulation on the inside of the wall. Furthermore details to involve the new windows into the insulation had to be solved.



Calculation of the wall temperatures (joint of floor and external wall). Left: without insulation. Right: with 5 cm insulation



Embedded windows

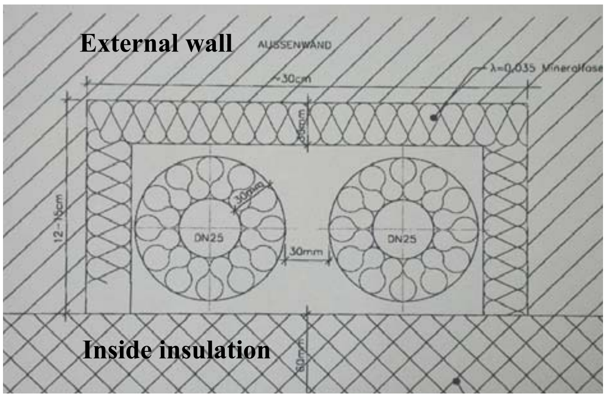
The ribbed concrete ceilings in the newer part of the old building and the wooden beams in the older part of the old building have cavity insulation over their entire surface. The rib ceilings got also an additional 50 cm wide insulation strip along the exterior walls. Since the adjoining internal walls are timber-framed, an additional insulation strip wasn't necessary there.

1.5.2 Heating

The old heating pipes were all situated in the external wall, partially without any insulation. Therefore the system had a lot of distribution losses. This system was completely replaced.

External walls with the old heating pipes, partially without any insulation

It was a demand of the building department not to have pipes in the floor. Furthermore, the double layered floor of the old building consist of a dry floor pavement on a dry fill with a total height of about 7-8 cm. Insulated Pipes wouldn't have been possible in this height. Therefore, the new heating pipes were installed in the external walls again.



The new heating pipes (double insulation)

In parts the distance from the pipes to the exterior surface (no external insulation) only amounts to 10 cm. Therefore additionally to the standard 30 mm insulation of the pipes itself another insulation board with 30 mm was attached into the slots. Thereby the heat losses were reduced.

1.5.3 Ventilation

At the proposal time the ventilation system was planed with a heat recovery rate of 60 %. During the design phase the team decided for a system with a better heat recovery rate of over 80 % for both ventilation systems.

1.5.4 Solar Thermal & Solar PV

During the planning process, various applications of PV systems were investigated according to their efficiency, costs and architectural appearance. Originally it was planned to integrate a photovoltaic-plant with a size of 100 m² within the glass roof of the atrium. During the planning period there was a decision against the glass roof and for several roof skylights. Therefore the photovoltaic-cells now are installed on the flat roof of the new building. As the area of 100 m² was not reduced, the energy gains by the PV-system are now higher than originally expected; because the glass integrated system is not as efficient as the now chosen one.

Theoretically the whole amount of electricity produced at Filderhof is put into the electrical grid and the electricity demand of Filderhof must be received from the conventional power supply system. Therefore the whole amount of electricity use has to be paid to the energy provider. The electrical power produced at Filderhof is taken separately and will be paid by the energy provider with a special prize for renewable energies. The building is supplied over low voltage (400 V). Because the transformer between Filderhof and the middle voltage grid (10 kV) means a physical barrier, in reality the power from the PV-system surely is directly used at Filderhof

Mounting of the solar thermal system

The thermal solar system was installed on the roof of the old building. Two thirds of the collectors are mounted on the south east side, one third on the west side. The System was carried out as an “on-the-roof-construction”. The meter of the solar system was defect for a while and did not quantify any heating energy. For that reason the real energy production within the first year could not been assessed.

1.5.5 Lighting systems

At first for the lighting of the atrium a large glass roof was planned. For financial reasons the dimension of the glass had to be reduced to a necessary minimum for day-lighting. As a result there are only some skylights integrated in the roof. This has substantial thermal advantages, because the U-value of the glass would be considerably higher as the U-value of the roof and thereby the heat losses in wintertime are now reduced. Additionally the danger of overheating in summertime is reduced.

1.5.6 CHP

After the starting up on the 22nd November 2006 the CHP wasn’t in use for a while at first, because the building was not used so far. As the automatic for filling up oil was defect there was an oil leakage during this time. When there was a new starting up in May 2007 the leaked oil burnt uncontrolled and caused a strong smoke expansion. The automatic for oil filling up was replaced on guaranty. Unfortunately on the top of that the CHP lied idle for a longer time whilst the technical staff was away for a planned absence. The substitution staff did realize the fault of the CHP but the building was sufficiently heated by the boiler and therefore there were no complaints by the staff. By now the substitution staff is sensitized that the failure of the CHP does not put the energy supply at risk but it has a bad influence on the economical run of the system. The experience has shown that a fault normally is fixed within three days.

1.6 Monitoring

1.6.1 Monitoring plan

The energy- and water consumption of the whole real estate is measured on one side by the meters of the energy supplier and on the other side by meters, which gauge the energy production of the technique in the building (solar PV, solar thermal, electrical power from the CHP). At Filderhof there is a special difficulty given because in addition to the retrofit of the old building there was a new building added. In any further assessment the new building has not to be taken into account and therefore it's consumption has to be deducted from the total. Usable consumption values are available since 04/26/2007. Therefore the evaluation period was set from 04/26/2007 to 04/26/2008. Normally there are daily measurements available, sometimes there are even 15-minutes figures given.
The following meters and sensors are installed in the Filderhof and connected to the Texem-plant. Therefore their measurements are transferred to the SECM (Stuttgart Energy Control Management) automatically.

Gas meter (GM):
- Total gas meter
- GM for CHP

Meter for heating consumption:
- Total heating-energy meter (HEM)
- HEM Solar
- HEM CHP
- HEM for DHW
- HEM retrofitted area (RA)
- HEM ventilation system (VS) bathrooms
- HEM VS kitchen

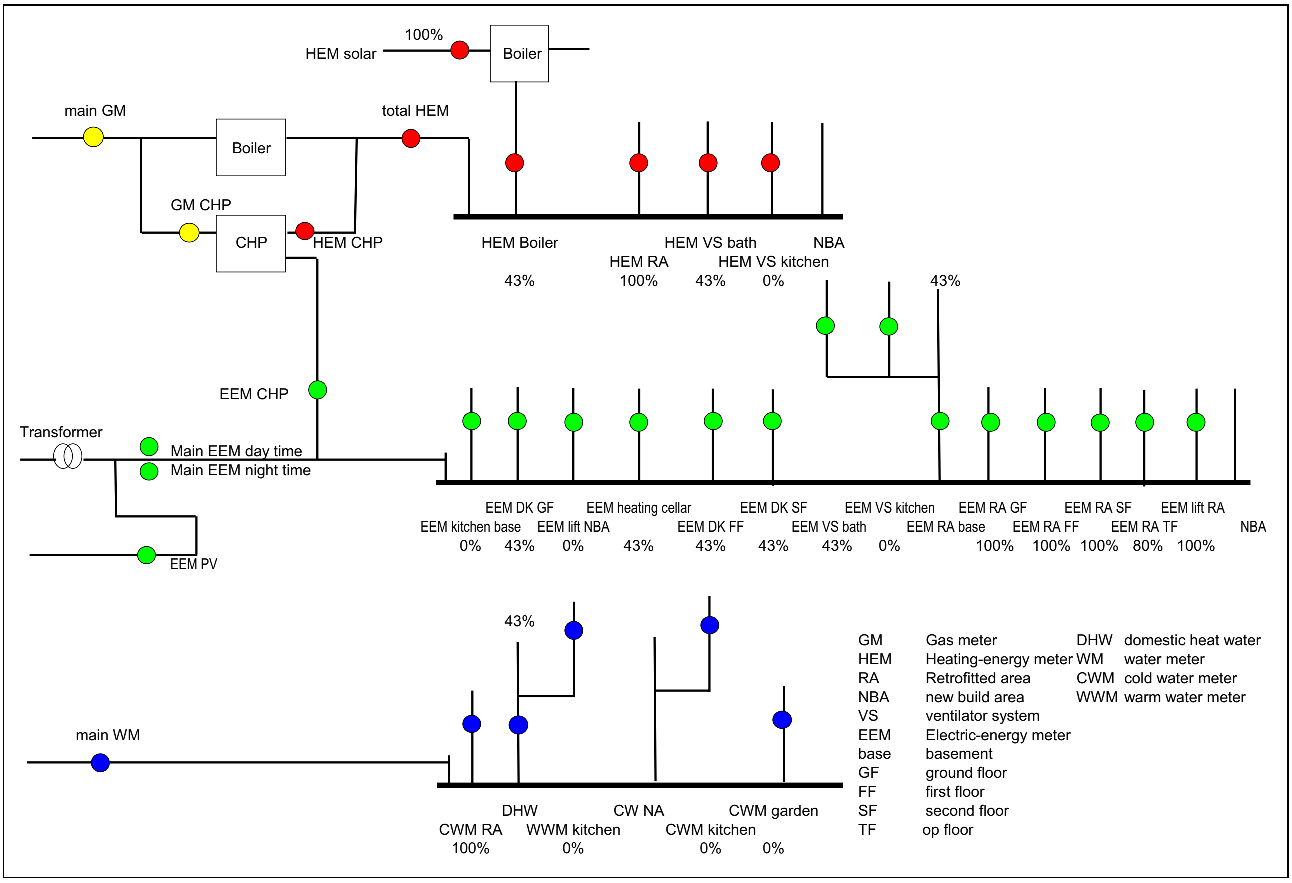
Meter for electricity consumption:
- Main electricity-energy meter (EEM) at mean time
- Main EEM at night time
- EEM CHP
- EEM Photovoltaic
- EEM heating cellar
- EEM lift RA
- EEM lift new build area (NBA)
- EEM VS kitchen
- EEM VS bathrooms
- EEM RA basement (base)

- EEM RA ground floor (GF)
- EEM RA first floor (FF)
- EEM RA second floor (SF)
- EEM RA top floor (TF)
- EEM kitchen base
- EEM distribution kitchen (DK) GF
- EEM DK FF
- EEM DK SF

Meter for water consumption:

- Total water meter (WM)
- Cold water meter (CWM) for domestic heat water (DHW)
- CWM RA
- CWM garden
- warm water meter (WWM) kitchen
- CWM kitchen

The following diagram gives an overview about the meter set-up. There are also factors shown which are needed for calculation of energy values from the meter values at Filderhof.



The weather measuring data used for correction of outdoor temperature was taken from Stuttgart´s meteorological survey station Schnarrenberg (314 above NN, 48.8° northern latitude, 9.2° eastern longitude). Those statistics are used as daily figures for the energy management of all buildings of the city of Stuttgart. The figures about the solar radiation come from a survey station in Stuttgart-Möhringen and are also available daily.

To find out about comfort there were measuring instruments for temperature and humidity installed in several rooms for about 10 days (from 04/17/08 to 04/28/08). The air quality was measured exemplary in one room with a CO_2-meter over a period of one week (from 04/17/08 to 04/24/2008). The measuring interval was every 5 minutes.

1.7 Data analysis

1.7.1 Local Weather

The local weather in Stuttgart is represented by the analysis of the meteorological of the survey station Schnarrenberg. For the calculation of the energy need the German regulation "EnEV" refers to the climate data's in the standard DIN V 18599. A comparison of standard and real temperatures is shown in the following table. It can be seen that especially in wintertime the local weather in the monitored period was warmer than the values given by the German standard.

	local temperature			**DIN V 18599**	**Difference**
	max [°C]	**min [°C]**	**mean [°C]**	**mean [°C]**	**[°C]**
April 07	26.6	0.2	13.7	9.5	4.2
May 07	6.8	28.1	15.8	12.9	2.9
June 07	29.0	9.7	18.6	15.7	2.9
July 07	35.6	10.5	18.8	18	0.8
August 07	30.7	7.7	18.2	18.3	-0.1
September 07	25.8	5.3	13.6	14.4	-0.8
October 07	23.7	-0.4	9.8	9.1	0.7
November 07	12.9	-3.3	4.2	4.7	-0.5
December 07	13.7	-8.9	1.6	1.3	0.3
January 08	13.3	-10	2.2	–1.3	3.5
February 08	18.2	-5.8	5.0	0.6	4.4
March 08	22.0	-4.7	5.8	4.1	1.7
April 08	26.6	0.2	14.2	9.5	4.7

Comparison of standard and monitored temperatures

The measured degree days in the monitored period runs up to 3'351.6 Kd. Compared to the reference degree days for Stuttgart of 3'555 Kd there is a difference of minus 5.7 %. The total solar radiation in the monitored period adds up to 1'296.1 kWh/m², whereas the reference data in the German Standard (DIN V 18599) has 1'216 kWh/m² (south orientation, 30 % inclination).

	Local radiation	**DIN V 18599**	**Difference**
April 07	204.5	151.2	53.3
May 07	157.0	158.5	-1.5
June 07	155.6	180.0	-24.4
July 07	160.9	187.5	-26.6
August 07	144.4	138.4	6.0
September 07	113.2	113.0	0.2
October 07	91.5	69.2	22.3
November 07	45.3	39.6	5.7
December 07	51.4	23.1	28.3
January 08	53.8	37.9	15.9
February 08	103.6	45.0	58.6
March 08	101.3	73.7	27.6
April 08	108.7	151.2	-42.5

Comparison of monitored and reference solar radiation

In 2007 the solar radiation in April was very high compared to the reference, whereas the radiation in April 2008 was very low. The measured intensity of the radiation from April 2007 to March 2008 in another survey station in Stuttgart was 13 % higher than the average there between 1961 and 1990, what is used as reference.

1.7.2 Energy consumption

As can be seen in the monitoring scheme, every meter which counts the total consumption of both building parts (retrofitted and new building) has to be split up into 43% for the retrofit building. Furthermore the kitchen is subtracted, as the Filderhof hasn't had an own kitchen before the retrofit. Only the kitchenette on each floor is calculated.

1.7.2.1 Energy Demand: Electricity

	[kWh/m^{2}a]	Total annual (kWh)	
Total electricity	33.8	72'120	E1
Electricity consumed by ventilation	5.3	11'251	E2
Electricity consumed by heating	1.1	2'369	E3
Electricity consumed by cooling	No cooling		E4
Electricity consumed by DHW	Auxiliary energy for DHW is included above		E5
Electricity of kitchen or special high-energy units	3.5	7'499	E6
Electricity consumed for lighting	No separate measurement		E7

1.7.2.2 Energy Demand: Thermal

	$[\mathrm{kWh/m^2a}]$	Total annual (kWh)	
Total incoming heating energy (district heating/solar/gas/oil), measured from the main supply line (temperature drop/flow vs. oil/gas consumption*Heating value)	52.8	112’482	T1
Heating energy consumed by ventilation	0.8	1’615	T2
DHW	21.6	46’130	T3

The values of the various heating meters of the old building were extrapolated with the boiler efficiency of 87 %. The boiler efficiency was calculated from the difference between the meters for total heating energy and the CHP heating energy and the difference of the total gas meters and the gas meter of the CHP. In that way the heating energy supply was mathematically equalized with an “only-boiler-system”. The characteristic value for the incoming heating energy was climate corrected with degree days, not including the DHW requirement.

1.7.2.3 CHP

	Total annual	
Fuel consumption (oil/gas) (Litres, m^3)	34’929	FC
Primary Energy (CHP)	371’004	$PE_{CHP} = FC * H_l$
Thermal energy delivered at the building (kWh)	181’730	th_{CHP}
Electricity produced	88’503	El_{CHP}
Electricity delivered at the building (kWh)	72’120	$E1 = El_{CHP} + El_{Grid} - El_{sold}$
Electricity to the grid (kWh)	16’383	El_{sold}
Electricity from the grid (kWh)	0	El_{Grid}

pef_{tot} = Total system performance factor,

$$pef_{Tot} = \frac{El + th}{PE_{CHP} + PE_{Grid} + PE_{GB}} = \frac{El_{Grid} + El_{CHP} + th_{GB} + th_{CHP}}{PE_{CHP} + PE_{Grid} + PE_{GB}} = \frac{\mathrm{FE}}{\mathrm{PE}}$$

where:

CHP	Combined Heat and Power
GB	Gas boiler instant system for space heating
El	Electric Energy (kWh)
th	Thermal Energy (kWh)
El_{Grid}	Electric Energy supplied from the grid (kWh)
El_{CHP}	Electric Energy supplied from the CHP (kWh)

th_{GB}	Thermal Energy supplied from GB (kWh)
th_{CHP}	Thermal Energy supplied from CHP (kWh)
FE	Final energy, electricity and heat as delivered to the individual or cluster of buildings (kWh)
PE	Primary energy (kWh)

$$pef_{Tot} = \frac{El + th}{PE_{CHP} - PE_{Sold} + PE_{GB}} = \frac{88'503 + 181'730}{371'004 - (2.7 * 16383) + 0} = 0.83$$

The electric energy which is produced by the CHP and the PV amounts to 98’973 kWh (88’503+10’470) in the monitored period and was therewith higher than the electricity consumed in the retrofitted part of the building. The same applies to the thermal energy where the sum of CHP and solar thermal amounts to 201’080 kWh (181’730 + 19’350). If we credit the retrofitted part of the building with the whole produced energy, now the retrofitted building produces more energy than it needs.

	Total annual		Renewable fraction	
Solar Thermal	19’350	R1	42%	R1/T3 (R1/T1)
PV	10’470	R2	15%	(R2+R3)/E1
Wind power	no	R3		

For a technical defect the solar energy meter did not work between the 06/01/07 and the 07/14/07 and from 08/02/07 to 08/28/07. Therefore the consumption in this period was replicated with a comparison to the PV-electricity meter. The so calculated thermal energy value is 6,150 kWh. This value was added to the measured value of 13’200 kWh.

1.7.2.4 Water consumption

		Total for the whole building
Water	1.1 m^3/m^2a	2 422 m^3/a

1.7.2.5 Primary energy calculation

The thermal energy demand amounts to 112’482 kWh, whereof 46’130 kWh are used for the domestic hot water. The DHW is supported by the solar thermal system with 19’350 kWh. The remaining demand (93’132) is supplied by CHP. As the delivered energy by the CHP (181’730 kWh) is higher than the remaining demand, there’s a surplus of energy which is delivered to the new building. The Electricity demand amounts to 72’120 kWh, whereof 10’470 kWh are produced by the PV. As the CHP produces 88’503 kWh, the surplus is again delivered to the new building.

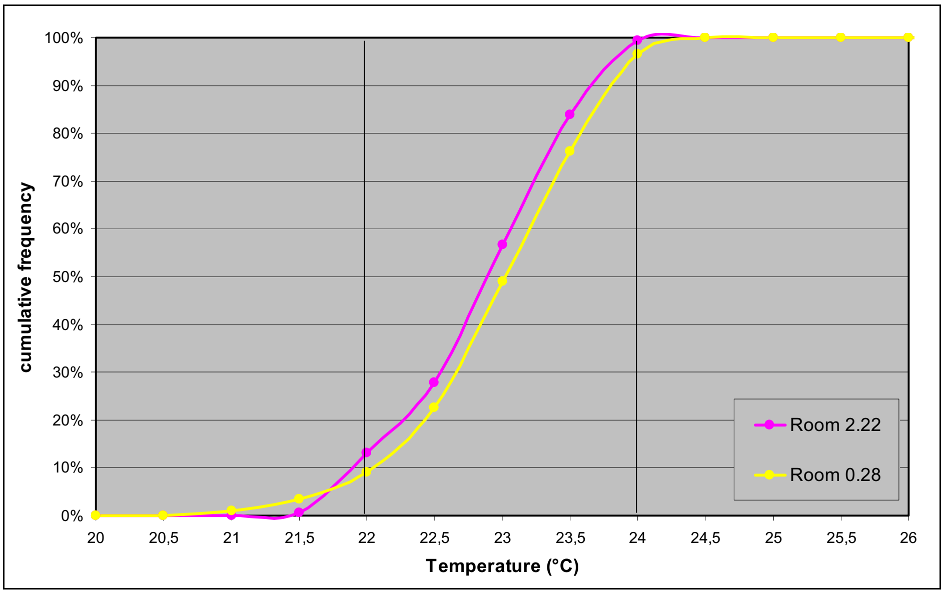
The delivered heat and electricity energy of the CHP may be counted separately, but not the gas input. Therefore it was the decision, that 75% of the gas input to the CHP will be contained in the space heating and the rest (25 %) in the electricity. With this approach, the primary energy factors of the CHP are:
Thermal: 75% · 371’004 / 181’730 = 1.53
Electric: 25% · 371’004 / 88’503 = 1.05

	kWh/m2 a	**Total for the whole building [kWh/a]**
Space heating	47.7	101’594
DHW	19.2	41’004
Electricity	30.3	64’609
Total	97.2	207’207

Space heating = (112’482 – 46’130) · 1.53
DHW = (46’130 - 19’350) · 1.53
Electricity = (72’120– 10’470) · 1.05

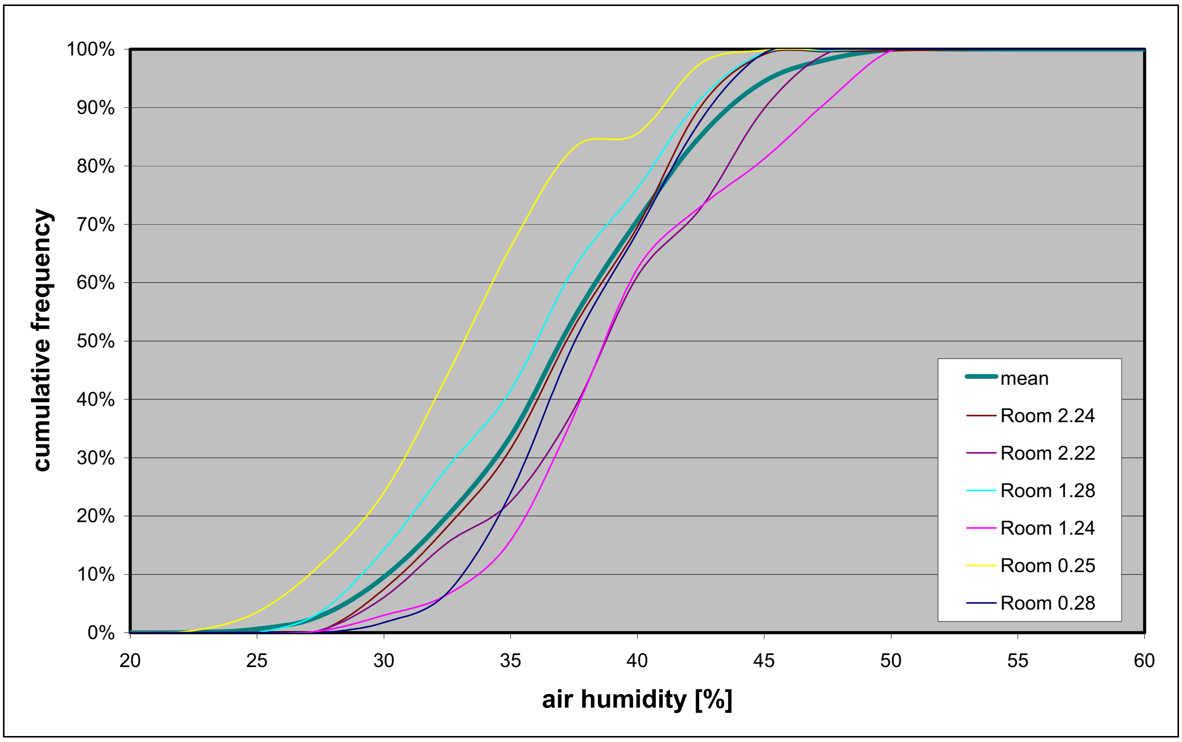
1.7.3 Thermal comfort

1.7.3.1 Calculated on the basis of measured data



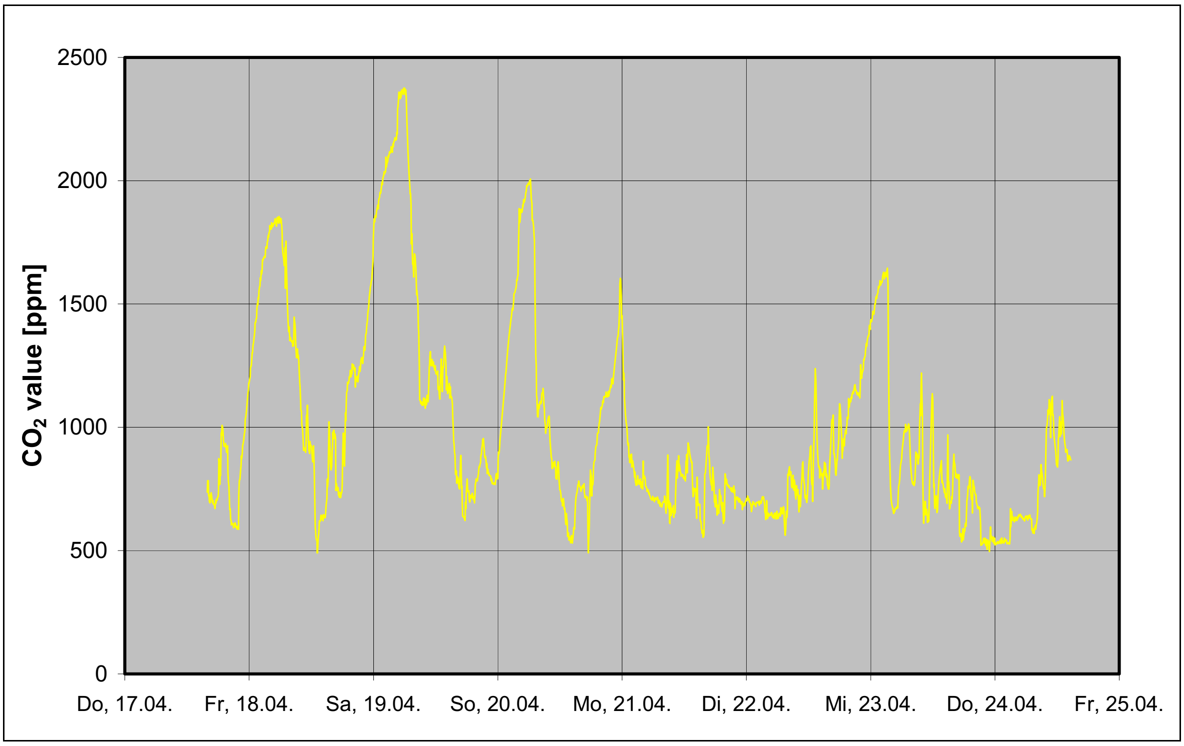
Cumulative frequency curves of Air Temperature during the whole day.

The average outdoor temperature during the monitored period was about 11.5 degree Celsius. The measurements of the room condition show, that the values required by the thermostat valve were reached. The differences come from the closing pattern of the valve.



Cumulative frequency curves of room humidity

The cumulative frequency of the room humidity shows that for about 30% of the time there is less than 35% humidity in the room. The maximum room humidity is 45 %.



Measuring of the CO_2-value in an exemplary double room

The diagram above shows the measuring of the CO_2-value in the air of an exemplary room with two persons. Within the first some days there is a strong peak during the night obvious. All of the sudden at 7.30 a.m. the value drops because the nursing staff opens the window for airing the room.

1.7.3.2 Reported on basis of users satisfaction enquiry

An interview with 12 users was done to find out their approval of Filderhof after retrofit. The users are residents and employees (nursing staff and office staff), but they are different form the users before retrofit as the former users weren't removed to the Filderhof.
In wintertime all users felt the room temperature principally pleasant (67 % of the staff and 83 % of the residents). In summertime there was a difference: Half of the staff approved of the room temperature, but only one third of the residents did so. Two-thirds of the residents felt too hot in summertime. This is strange, as it's contrary to the interview before the retrofit. All of the staff and an 83 % - majority of the residents was happy with the air quality. The odour of the stock did not become conscious at 75 %. As anticipated the mix of odours such as the smell of food and persons etc. was recognized more by the staff as by the residents (no resident recognized it, 50 % of the staff recognized an usual smell).
The questions about the habits with the natural ventilation in the rooms were answered much more distinguished after refurbishment. As an average over the day the interviewed declared they had their windows sometimes tilted at 52 % and sometimes wide open at 29 %. So the windows aren't any more always open, just because of a habit. It has to be mentioned that the windows are closed at 75 % at night time (please take a look at the CO_2- measurement). Questioned about the person who opens the windows 96 % of the interviewed answered the staff would do it. Only 4 % of the residents open their window themselves (before retrofit, 30 % of the residents did it).
The new windows were assessed as not draughty by all interviewed. Having a shower and a toilet in their own room was appreciated by nearly all of the interviewed. All users considered the rooms to be bright and the size of the windows quite right. 58 % of the residents made known they would leave the electrical light on for 3-4 hours a day, 25% said

they leave it on for 5-6 hours a day. 33 % of the staff declared they use electrical light for 3-4 hours a day and 33 % of the staff used it for more than 7 hours a day, because they have service rooms without daylight.

75 % thought the corridors were illuminated agreeably. The lounge was too hot in summer time for most of the residents (83 %), most of the staff agreed with the temperature. The tram passing by was not heard by 50 % of the interviewed. Of those who had heard it assessed 50 % the tram as noiseless and 50 % as loud. Nobody said the tram would be very loud.

1.7.4 Overall User Satisfaction (gender specific surveys on indoor environment conditions)

The overall user satisfaction is very good as can be seen in the chapter before. The users now have their own shower and a toilet in their rooms and the new windows aren't draughty anymore. Furthermore the windows have acoustic glazing, what means that the tram passing by isn't that audible anymore.

1.8 Summary

1.8.2 Foreseen and Obtained Energy and water saving

The obtained energy savings are calculated by the difference between year 2004 and the measured energy from 04/26/2007 to 04/26/2008.

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, heating	194	271.1	411 800	547 636

The obtained heat energy savings are significantly higher than predicted. For this it must be explained, that by adding an extension to the building, many former external walls are now inner walls. Thereby the heat losses are reduced. This wasn't calculated in the predicted energy savings.

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, electricity	56	78.4	120 200	157 987

	Predicted [m^3/m^2 a]	Obtained [m^3/m^2 a]	Predicted [m^3/a]	Obtained [m^3/a]
Water saving measures	0	0	0	0

1.8.3 Overall energy and water consumption and improving comfort evaluation

	Before retrofit (2004)	After Retrofit Foreseen	Saved foreseen	After Retrofit Measured	Saved measured
Primary Energy [kWh/m^2 a]	396.8	176,8	220	97,2	299,6
Water [m^3/m^2 a]	1.794	1.794	0	1.133	0.661

The primary energy after retrofit amounts to 207’207 kWh per year and therefore to 97,2 kWh/m²a. As it was foreseen to reduce the primary energy to 176.8 kWh/m²a, the obtained achievement is much better than expected. For this it must be explained, that by adding an extension to the building, many former external walls are now inner walls and the total floor area of the old building was reduced from 2875 m² to 2131m². Thereby additional energy savings were achieved.

1.9 Overall economic evaluation

Total extra costs (Foreseen) [EUR]	Total extra costs (Observed) [EUR]	Saving (Foreseen) [EUR/a]	Saving (Observed) [EUR/a]	Payback period foreseen	Payback period observed
789 100	924 222	38 600	45 836	20.4	20.2

Energy costs used for calculation (2008):

Gas:	0.0637	€/kWh
Electric	0.130	€/kWh
Input to the grid (PV):	0.5180	€/kWh

In this project the calculation of the costs was linked with a separation into costs for the retrofit of the old building and the construction of the extension building. As a lot of work (e.g. lighting) was done by one firm for the whole building complex there was often only one bill for all. This caused a lot of work at calculation of the costs for the BRITA project. Finally the total eligible costs of the energy saving measures amount to 924’222 €, when 789’100 € were predicted. The cost overrun was mainly caused by the insulation of the exterior walls, the windows, the heating system and especially by the ventilation system. Additionally the planning costs rose. In contrast, the PV and the insulation were cheaper than predicted. In the end, we have 1.39 Mio € eligible costs for the total BRITA project (construction, design reporting and monitoring), when 1.23 Mio € were predicted. The difference in total costs is also the result of our special situation in having a retrofit combined with the construction of a new building. In the obtained savings, only the energy costs are considered. The difference in maintenance costs isn’t included.

1.10 Lessons learned

- Architectural aspects (influences) may have a strong influence into the retrofit concept even if a building is not listed. In the case of Filderhof an external insulation could not be realised. An internal insulation on the external walls was advised. This led to less energy savings and results in more planning work on details in order to prevent thermal bridges.
- Economic influences may change the material used for building parts. At Filderhof, the glazed atria roof has now only small skylights. The architects had to react on the situation and transferred the planned PV system to the opaque roof parts. This had an positive effect on the energy savings and the gains of the PV system.
- The use of rooms in the cellar has to be carefully planned in order to keep the heated zone as compact as possible. However, the given situation and necessary functions of rooms may be more important for the building owner than the energy efficiency.
- The planning process over five years requires changes in the retrofit measures of a building. Therefore detailed information about the planned measures and the resulting energy savings at the proposal time of the EU project is not always possible.

Necessary modifications at the retrofit measures have to be presented and elaborated at the Commission. The time spent on that and on the waiting for the decision, delays the planning process of the project.

- There is a lot of coordination work to be done with several partners of the project inside the city and especially with financial government. Thus the project time enlarges to five years from the earliest planning phase up to the end.
- The combination of a retrofit with the construction of a new building makes sense for the improvement of the situation in an old nursing home. Therewith an efficient and innovative system may be applied, which wouldn't be realised in this scale if only the retrofit had be done.
- It is necessary that the operation staffs are trained in energy efficiency. It has to be explained to them, when a special operation is necessary for the economical run of the system. This concerns also the substitution staff as was realised when the CHP in the Filderhof lied idle for a longer time while the main staff was away.
- If the retrofit of an old building is combined with the construction of a new building, the calculation of retrofit costs and energy savings is very complicated. Also the separate estimation of costs for the old building is difficult as there are many costs belonging to the old building but occurred by the addition of the new building.
- As the BRITA-project requires "Bringing Retrofit Innovation to Application", some special "innovations" and therewith expenses are made. Unfortunately the long time between spending the money and getting the allowance by the EU wasn't taken into account before. This resulted in not expected interest costs.
- With this project it was shown, that it is possible to reduce the primary energy of existing buildings by over 50 %
- The minimized energy consumption can be supplied with renewable energy in the order of 22 %.

2. City College Plymouth

Previously: Plymouth College of Further Education

Author: Gilbert Snook, Head of Estates

2.1. General data

2.1.1. General information

Year of construction	1972
Year of renovation –	see paragraph 1.14
Number of storeys	8
Heated volume	17352m^2
Total volume	18183 m^3
Gross internal floor area	6061m^2
Useable floor space	5784m^2

2.1.2. Site

Urban

Latitude	50:22:26°N
Longitude	4:10:03°W
Altitude	19.9m above sea level
Mean annual temp	10.6°C
Mean winter temp	6.3°C
Climate description	Temperate

2.1.3. Building Type

Education and Research

2.2. Project Reduction

The demonstration project was taken to the end of detailed design when the refurbishment of the Tower Block was cancelled in February 2006. This was at the instigation of the British Government's Education Sector funding body called the Learning and Skills Council. The financial position of the college had deteriorated and the agreed recovery plan required the college to prepare a new property strategy.

At the point of cancelling the Tower Block refurbishment, it was agreed with the BRITA-in-PuBs Steering Group and the EU that the college should remain a demonstration partner and provide the following:-

- Full design report.
- BRITA Information Tool base on the completed Tower Block design and full information for the Wind Turbines which were installed.
- General contribution into other Work Packages .
- Significant input into Work package 9.
- Final Report on the Wind Turbines.

2.2.1. Design Report

The complete design report can be found in Appendix A. Reference should be made to www.brita-in-pubs.eu to see the BRITA Information Tool.

2.2.2. Wind Turbines

The rest of this final report presents the outcome of the installation of the wind turbines, the only element of this demonstration project taken through to completion.

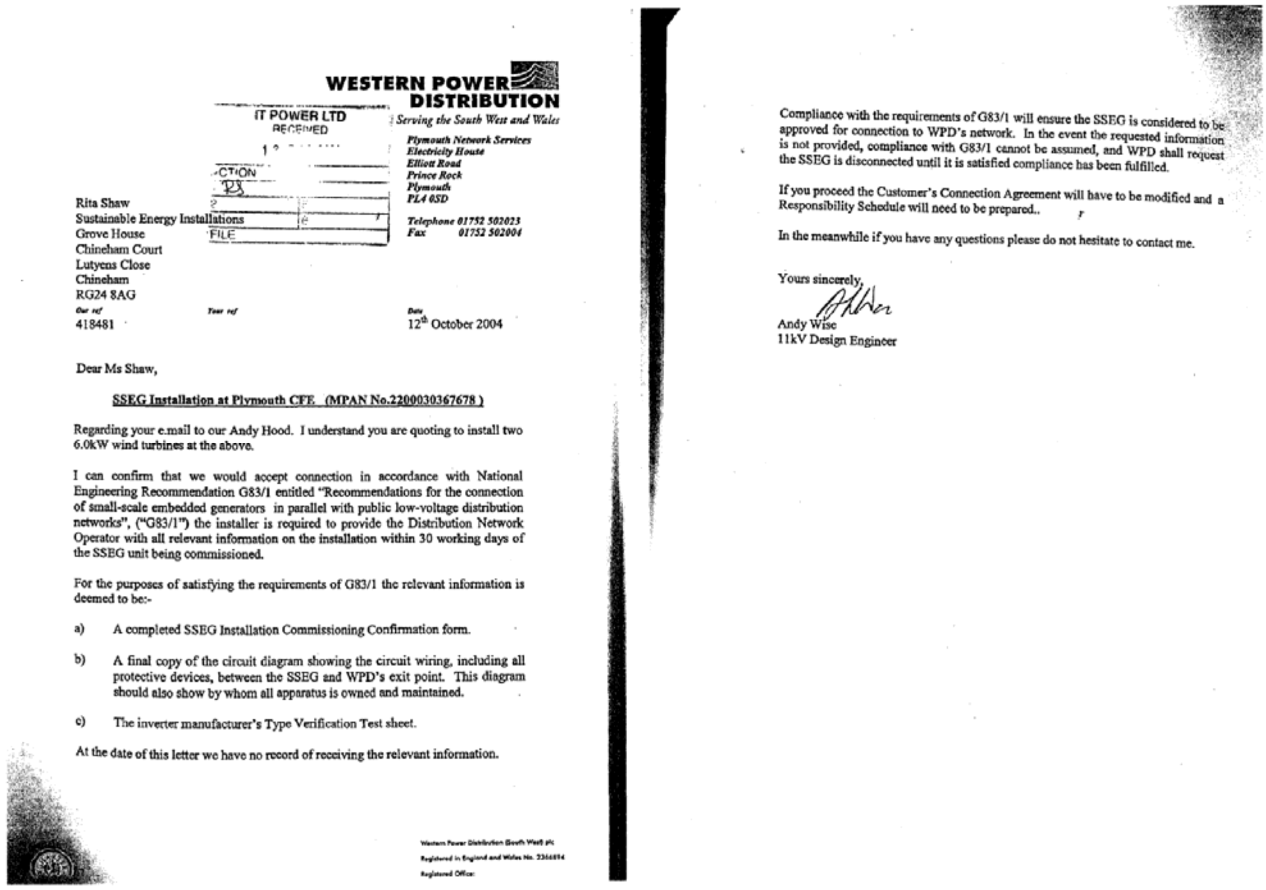
2.3. Before Retrofit

The wind turbines were planned to be installed on a modern extension to the main Tower Block called the Innovation Centre.

During the construction of the Innovation Centre some preliminary works took place. The original structural engineer verified the steel frame structure would be suitable to receive the wind turbines. This included the installation of stub support columns.

2.3.1. Existing Electrical System

The Innovation Centre has a standard electrical system. Consent from Western Power Distribution was obtained for the turbines output to be directly connected via inverters to the existing supply.



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RS
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Rita Shaw
Sustainable Energy Installations
Grove House
Chineham Court
Lutyens Close
Chineham
RG24 8AG

Our ref 418481
Your ref
Date 12th October 2004

Dear Ms Shaw,

SSEG Installation at Plymouth CFE (MPAN No.2200030367678)

Regarding your e.mail to our Andy Hood. I understand you are quoting to install two 6.0kW wind turbines at the above.

I can confirm that we would accept connection in accordance with National Engineering Recommendation G83/1 entitled "Recommendations for the connection of small-scale embedded generators in parallel with public low-voltage distribution networks", ("G83/1") the installer is required to provide the Distribution Network Operator with all relevant information on the installation within 30 working days of the SSEG unit being commissioned.

For the purposes of satisfying the requirements of G83/1 the relevant information is deemed to be:-

a) A completed SSEG Installation Commissioning Confirmation form.

b) A final copy of the circuit diagram showing the circuit wiring, including all protective devices, between the SSEG and WPD's exit point. This diagram should also show by whom all apparatus is owned and maintained.

c) The inverter manufacturer's Type Verification Test sheet.

At the date of this letter we have no record of receiving the relevant information.

Western Power Distribution (South West) plc
Registered in England and Wales No. 2366894
Registered Office:

Compliance with the requirements of G83/1 will ensure the SSEG is considered to be approved for connection to WPD's network. In the event the requested information is not provided, compliance with G83/1 cannot be assumed, and WPD shall request the SSEG is disconnected until it is satisfied compliance has been fulfilled.

If you proceed the Customer's Connection Agreement will have to be modified and a Responsibility Schedule will need to be prepared..

In the meanwhile if you have any questions please do not hesitate to contact me.

Yours sincerely,

Andy Wise
11kV Design Engineer

2.3.2. Energy Use

To put the turbine output into context, the electrical consumption per annum, for the whole Kings Road campus is about 2,000,000 kWh/a. The annual electrical consumption for the Tower Block is 650,000 kWh/a.

2.4. Energy saving concept

The following is an extract from the Operations and Maintenance Manual prepared by Sustainable Energy Installations.

2.4.1. Overview/Description of the system.

The overall system consists of two kW roof-mounted wind turbines, and associated electrical equipment (namely controllers/rectifiers, inverters and switches), ensuring safety and power quality for the mains connection. Table 1 below gives details of the system installed.

1.2.4.1. Summary of system data

Wind turbines	Manufacturer	Proven Engineering
	Model	WT 6000
	Power rating	6kW
	Number installed	2
	Cut-in wind speed	2.5 m/s (5.6mph)
	Rated wind speed	12 m/s (25mph)
	Cut-out wind speed	None
	Mast	Self supporting, tilt down, height 9m
	Rotor	5.6m diameter, 3 blades
	Generator	Brushless, direct drive, permanent magnet, Nominal 300V
Inverters	Nominal AC power	2,750 W
	Maximum AC power	3,000 W
	Manufacturer	SMA
	Model	Windy Boy WB (SB) 3000
	Number installed	4 (two per wind turbines)
Mains connection	Protection	Integrated in inverter (over/under voltage, over/under frequency and islanding protection)
		Over voltage 264V
		Under voltage 209V
		Over frequency 50.5 Hz
		Under frequency 47Hz
	Engineering Recommendation	G83/1 – see note [1] below

2.5. System design

2.5.1. Physical layout

The two wind turbines are mounted on the roof of the Innovations Centre building, as shown in Figure 1.

---

[1] The system installed falls just outside the scope of Engineering Recommendation G83/1. However, Western Power Distribution (the DNO) agreed to apply G83/1 to the installation.

Figure 1 Wind Turbines on the Roof

Three-phase AC cables are routed from each wind turbine to the controllers (see Figure 2) and inverters (Figure 3), which are located in the plant room on the second floor (water storage tanks). AC isolators are also installed near the inverters (see Figure 4).

Figure 2 Wind Turbine Controller

Figure 3 Inverter

Figure 4 AC Isolators

AC cables are routed from the plant room on the second floor (water storage tanks) to the distribution board in the plant room on the ground floor, where the main incomer is situated. Dedicated MCBs for the wind turbines, a lockable three-phase AC isolator as well as a kWh meter are located adjacent to the distribution board, as shown in Figure 5 and Figure 6.

Figure 5 MCBs

Figure 6 Lockable Isolator and kWh Meter

2.5.2. Mechanical Design

The wind turbines are mounted on a 9 m self-supporting tilt down tower. The tower is mounted on an X-shaped girder base frame, which rests on stub columns which were provided during the construction of the Innovations Centre building. The base frame (see drawing in Annex B) was designed by Proven, with input from structural engineers Structures One. The structural engineers' calculations can be found in their report *Structural Final Calculations*, dated 17 June 2005.
A winch anchor point had to be provided for each turbine, for lowering and raising of the turbine.

2.5.3. Electrical design

The electrical installation conforms to BS7671 (IEE Wiring Regulations).
The wind turbines and base frames are earthed via the building's lightning protection system. The inverters are connected to the DNO earth.

The wind turbine generators generate three-phase AC power of nominal 300V. It should however be noted that the generator output voltage can be twice the nominal voltage under no-load conditions. The output from the generators is connected to a controller, which converts the three-phase AC to DC, and also contains an isolator. The conversion to DC is necessary because the generator output is not synchronised with the electricity grid.

The DC output from each controller is connected to two inverters. The inverters are sophisticated devices which convert DC power to AC power at high efficiency, and deliver AC power which is synchronised with the mains supply. They operate at up to 95% efficiency.

The inverters also contain important protection functions. They automatically cease generation in the event of a fault with the mains supply e.g. loss of supply, exceeding over or under voltage or frequency limits. The inverter automatically restarts 3 minutes after the grid supply is restored, or the grid frequency or voltage return to acceptable values. The inverters have been type approved in accordance with Engineering Recommendation G83/1 (the current recommendation for the connection of small generators to the electricity grid). AC cable then runs from the second floor plant room to the plant room on the ground floor, where it is connected to the building's electrical system via a kWh meter, a lockable isolator and MCBs protecting the AC wiring. This isolator is the main point of isolation for the wind turbine system.

Dual supply labelling and hazard warning labelling is provided throughout the installation.

2.6. Predicted energy generation/payback

Calculation source	Installation cost €	Wind speed	Annual output	Payback period (years)
BRITA proposal	75000	-	30000 kWh	25
Clear Skies grant application	82000	5.2 to 6 m/s	33800 kWh	24
Private recalculation	82000	5.2 m/s	13000 to 22000 kWh	63 to 37

Payback based on the 2004 assumption of electricity at €0.1/kWh.

2.7. Life Cycle Assessment

The following assessment was produced by Dipartimento di Ricerche Energetiche ed Ambientali (DREAM) Università degli Studi di Palermo

The assessment was based on a notional real output of 11500 kWh/year. Depending on the weather conditions in any year now the turbines are working without faults so this target could be achieved.

2.7.1. Brief description of the retrofit action

The action interested the Plymouth college with the installation of two wind turbines upon the roof of the building. Each turbine has a power of about 6 kW, at about 21m above ground level. It is important to note that the measured electricity output of turbines was much lower than predicted values, due to local disruption of air currents.

Primary energy saving and emissions			
Primary energy save (E_{year})	604798.0		[kWh]
Global Emission saving ($EM_{S\text{-}i}$)	117.3		[$ton_{CO2\ eq.}$]

Summary of materials employed and main components			
Component			
Galvanised steel	4.1		[ton]
Cables	25.0		[m]

Energy and Environmental Indexes			
Global Energy Requirements (GER)	26 653.0		[kWh]
Global Warming Potential (GWP)	6.9		[ton $CO_{2\text{-Eq.}}$]
Nutrification Potential (NP)	2.4		[kg PO_4]
Acidification Potential (AP)	32.2		[kg SO_2]
Ozone Depletion Potential (ODP)	0.1		[kg CFC_{11}]
Photochemical Ozone Creation Potential (POCP)	3.5		[kg C_2H_4]

Synthesis Indexes			
Energy Payback Time ($E_{\text{-PT}}$)	0.7		[year]
Emission Payback Time ($EM_{\text{-PT}}$)	0.9		[year]
Energy Return Ratio (E_R)	22.7		

Contributors to data survey:	Dr. Gilbert Snook
Life Cycle Analyst:	Fulvio Ardente

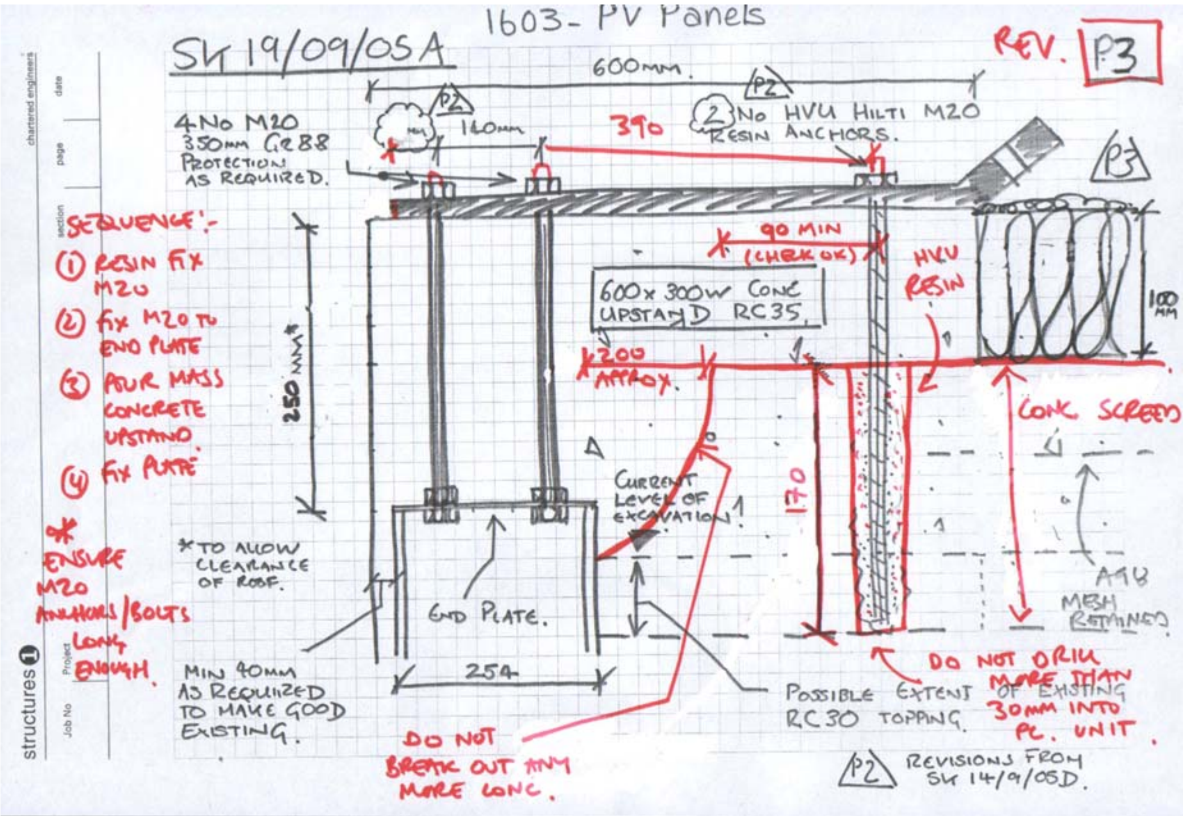
2.8. Construction Phase Description

The turbines were installed by the contractor, also responsible for the Clear Skies Grant and the design. The contractor's name is Sustainable Energy Installations.

The construction period was as follows:

- Winch anchor points week beginning 3 October 2005
- Electrical equipment week beginning 17 October 2005
- Transport of turbines from manufacture 24 October 2005
- Installation of turbines 25th and 26th October 2005

The one difficulty experienced during the installation was establishing the winch anchor points. Two were necessary, one for each turbine, to allow lowering of the units. The designers/installers did not properly investigate this matter in advance. A revised design had to be issued by the Structural Engineer. The revised detail was the main reason for cost over-run.



1.2.8.1. *Final winching point*

The construction period went smoothly , a Health and Safety Plan was produced that required the closure of the Innovation Centre Atrium during the short installation period. Therefore the works were co-ordinated with the college half term holiday.

1.2.8.2. Final Cost Analysis

Work stage	BRITA Budget €	Final cost 2008 €
▪ Planning consent and building Regs approval	-	7909
▪ Detailed design	8250	
▪ Supply and installation	75000	96424
▪ Specialist monitoring equipment	-	10687
▪ Health and Safety plan		1466

The reasons for the cost deviations are:

- Inflation since the BRITA Project application
- The late design of the winching point costing about €6170 extra
- The extra cost for specialist monitoring equipment
- Ancillary costs for Planning and Building Regulation approvals together with Health and Safety planning not allowed for in the original BRITA design costs

2.8.2. Post Installation Problems

- Malfunctioning automatic brakes. These brakes were fitted at the suggestion of the manufacturer so the turbines would automatically stop if destabilisation occurred due to turbine blade damage. These had never been fitted before by Proven and proved very unreliable. Proven later fitted a better braking system and replaced the blades with stronger composite material at no extra cost. The sticking brakes were repaired in May 2007.
- Hand braking system difficult to operate and unreliable. The college experimented with remote braking but they proved ineffective. A better hand braking system was fitted, at no extra cost by the manufacturer, in August 2007.
- The breakdown and eventual replacement of one inverter. The replacement occurred in May 2007.
- Poor customer support from both the installer and manufacturer. Defects were slow to be rectified. They were disinterested in the poor output figures.

2.9. Monitoring

The monitoring period was from 1st March 2007 to 29th February 2008.
The wind turbines were fitted with the following monitoring devices:

- Both turbines are remotely linked to the college energy consumption monitoring system called Satchwell Utilities Monitoring. The meters are remotely read utilising text messaging.
- As a back up the meters were read weekly.
- The west turbine is fitted with a data logo and weather station. This provides detailed information on wind speed, wind direction and turbine output prior to the inverters. The meters read output after the data logger.

Output data from meter reading is as follows.

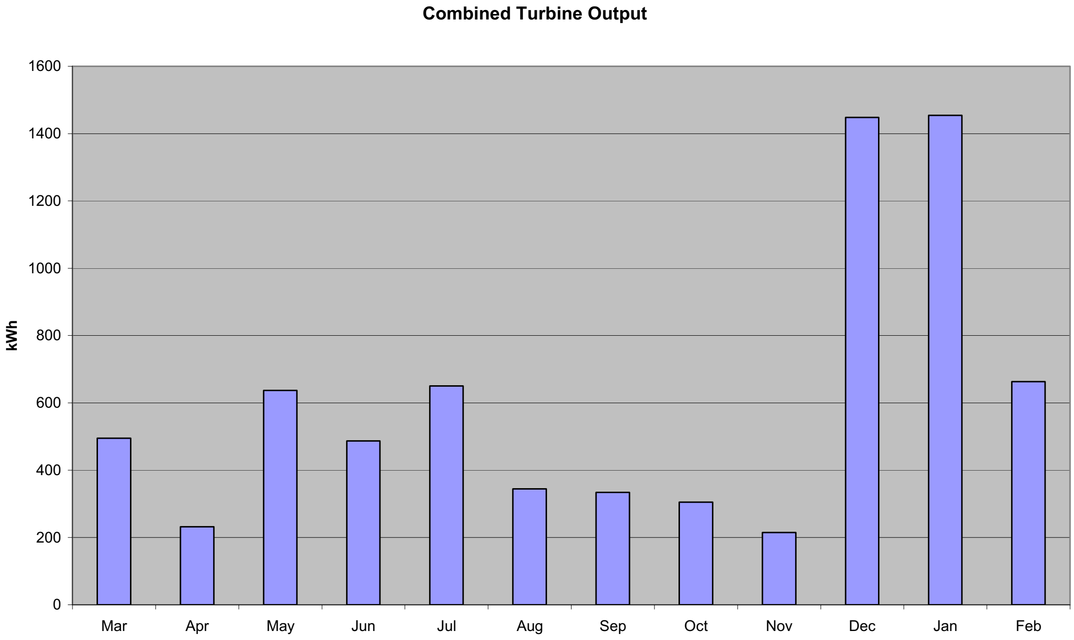
2.9.1. Combined Wind Turbine Output Analysis

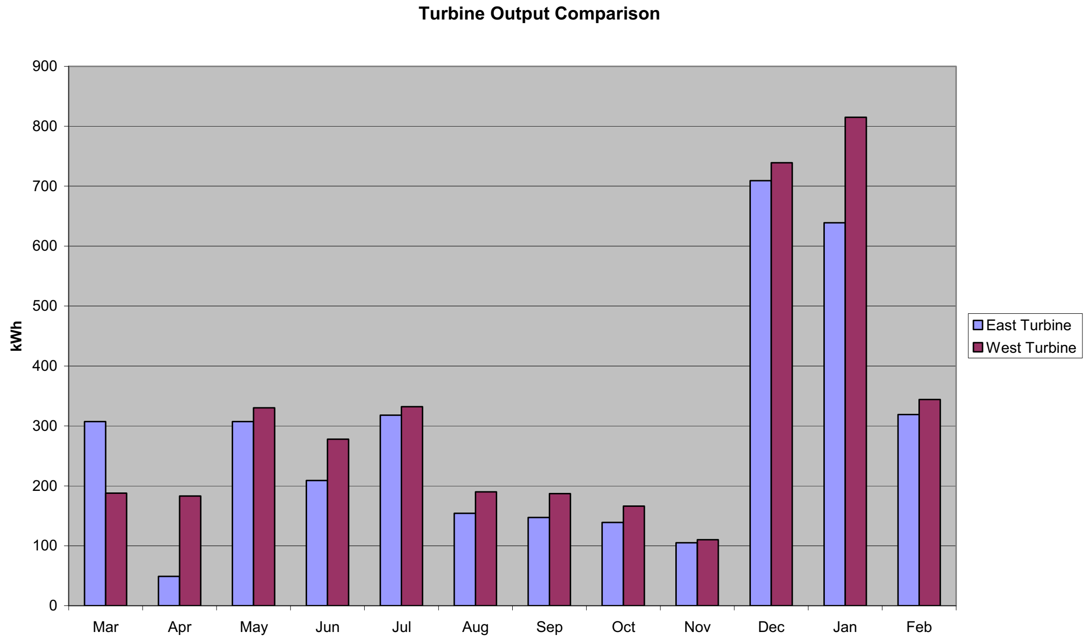
The data is collated from fixed kWh metering of the energy generated, where the meters are located after the inverters etc., therefore losses in the control gear are allowed for.
The turbine output comparison indicates generally, that the West turbine (Turbine B) has a greater generating capacity than the East. This is probably a function of the turbines relative location to the adjacent tower block building, and the incidental predominant wind direction.
This data is collected manually each day from fixed meters and will vary compared to the data logged at the turbine mast. This is because the logged data time reference is 00:00 hrs (ie

the time each day that the data runs from), however the manually collected data is recorded at random times which may be as much as 10 hours or more time difference.

TOTAL CUMULATIVE POWER GENERATED

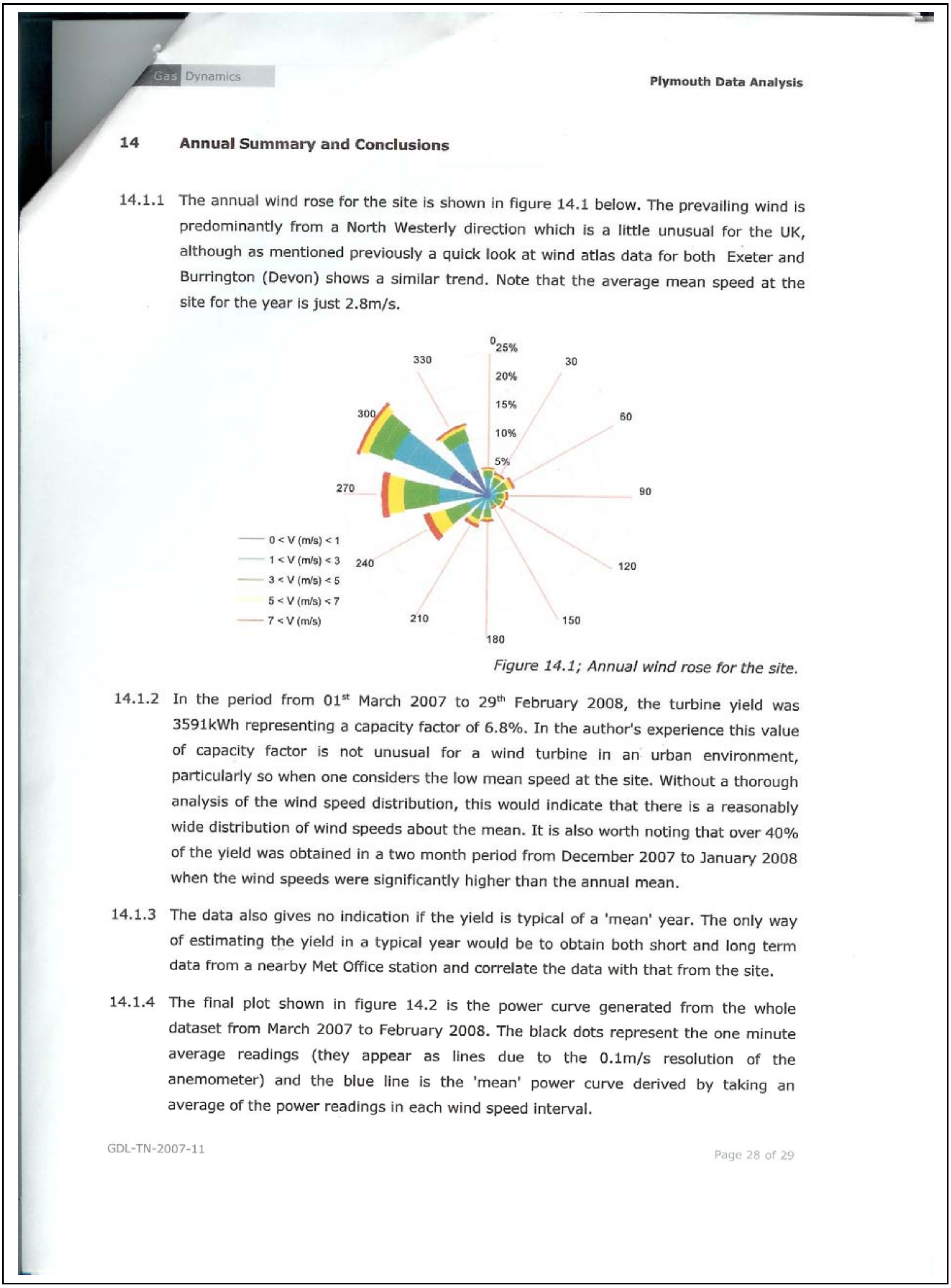
Month	Turbines A+B	Turbine A	Turbine B	Turbine B measured power generation before inverters
Mar	*495*	307	188	318
Apr	*232*	49	183	69
May	*637*	307	330	310
Jun	*487*	209	278	212
Jul	650	318	332	329
Aug	344	154	190	142
Sep	334	147	187	130
Oct	305	139	166	132
Nov	215	105	110	138
Dec	1448	709	739	745
Jan	1454	639	815	723
Feb	663	319	344	348
TOTAL (kW/h)	*7264*	3402	3862	3591





1.2.9.1. Output data from Data Logger fitted to West Turbine

Summary for the 12 month period is provided below and the whole report can be found in Appendix B.



14 Annual Summary and Conclusions

14.1.1 The annual wind rose for the site is shown in figure 14.1 below. The prevailing wind is predominantly from a North Westerly direction which is a little unusual for the UK, although as mentioned previously a quick look at wind atlas data for both Exeter and Burrington (Devon) shows a similar trend. Note that the average mean speed at the site for the year is just 2.8m/s.

Figure 14.1; Annual wind rose for the site.

14.1.2 In the period from 01st March 2007 to 29th February 2008, the turbine yield was 3591kWh representing a capacity factor of 6.8%. In the author's experience this value of capacity factor is not unusual for a wind turbine in an urban environment, particularly so when one considers the low mean speed at the site. Without a thorough analysis of the wind speed distribution, this would indicate that there is a reasonably wide distribution of wind speeds about the mean. It is also worth noting that over 40% of the yield was obtained in a two month period from December 2007 to January 2008 when the wind speeds were significantly higher than the annual mean.

14.1.3 The data also gives no indication if the yield is typical of a 'mean' year. The only way of estimating the yield in a typical year would be to obtain both short and long term data from a nearby Met Office station and correlate the data with that from the site.

14.1.4 The final plot shown in figure 14.2 is the power curve generated from the whole dataset from March 2007 to February 2008. The black dots represent the one minute average readings (they appear as lines due to the 0.1m/s resolution of the anemometer) and the blue line is the 'mean' power curve derived by taking an average of the power readings in each wind speed interval.

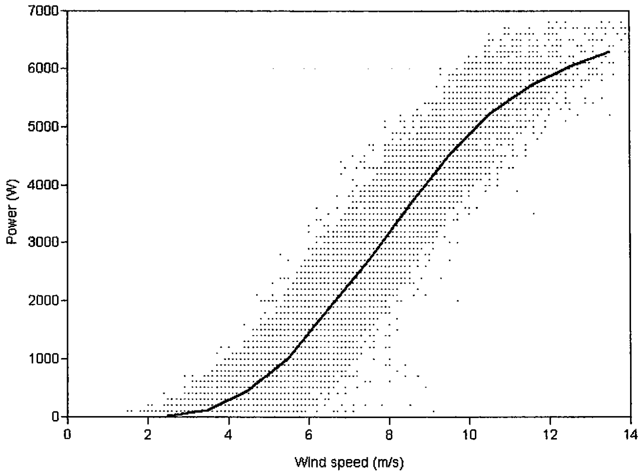


Figure 14.2; Power curve from the annual dataset.

14.1.5 Note that the maximum power output from the turbine is around 6.8kW, which is somewhat higher than the 6kW rating of the turbine. In the authors experience this particular turbine does generate 6kW *at the point it is connected to the grid*. It is unclear from the documentation where the power readings are taken, but they may represent the raw AC power of the turbine, which will not account for the losses in the rectifiers and inverters.

2.10. Data analysis

2.10.1. Local Meteorological Office Data

- Average annual windspeed for the Kings Road site 5m/s at 10m above ground level (Department for Business Enterprise and Regulatory Reform).
- The actual recorded wind speeds at the Plymouth Met Office Monitoring site are:-

April 07	3.9 m/s
August 07	4.5 m/s
September 07	4.2 m/s
October 07	3.7 m/s
November 07	4.1 m/s
December 07	7.0 m/s
February 08	5.4 m/s

- Wind Rose data from the Met Office Plymouth monitoring site for the 10 years 1994 to 2003 show a clear pattern of the main prevailing winds, throughout the year coming from the south west. They could not provide, at this stage, a wind rose diagram for the monitoring year.

2.10.2. Energy Generation

The annual output of only 7264 kWh/yr is very disappointing and it has been difficult to get any significant assistance from the manufacturer, Proven, to investigate the short fall.

The key issue in the monitoring year is wind speed. The lowest windspeed predicted for this roof was 5.2 m/s. The monitoring year revealed an actual average windspeed on only 2.8 m/s. The lack of wind will have a drastic effect on output. The following quote from BWEA helps to explain the problem.

“The power available from the wind is a function of the cube of the windspeed. Therefore if the wind blows at twice the speed, its energy content will increase eight-fold. Turbines at a site where the wind speed averages 8 m/s produce around 75 to 100% more electricity than those above the average wind speed is 6 m/s”.

A private recalculation using an Open University calculation model using the actual average wind speed of 2.8 m/s predicts an output 4400 kWh/yr but the model is said to be inaccurate at such low wind speeds.

The low windspeed seems to be due primarily to micro climate effects caused by the Tower Block. The original expectation was, this should not have a profound effect since the Tower Block is situated on the north side of the turbines, i.e. the opposite side to the prevailing wind. Also the local measurements show prevailing wind coming from the north west rather than the expected south west, reinforcing the impression of micro climate effects.

Other issues that have contributed to the low output are as follows.

- Lower than average autumn wind speeds during the monitoring year, September, October and November.
- The prevailing wind coming from the North West means the more easterly turbine output has been lower than the west turbine.
- Faulty equipment remained during the monitoring period through to and including May 2007.
- Some minor output was lost due to turning off the east turbine as a result of complaints of shadow flicker. The loss would have been minimal since this happened only during the summer months for very short periods.

- Invertor losses which seem to amount to about 10% of generated electricity. Also there is a lag in the operation of the inverters and they switch off when over generation occurs..

2.10.3. User Experience

The college's experience of owning and running wind turbines has been mixed and is summarised as follows:-
The erection of the turbines created a great deal of media and local interest. The turbines featured briefly in news programmes both on local television and radio. Detailed enquiries arrived from local business and the public sector nationally, on average, monthly throughout 2006 and well into 2007. This interest has now subsided.
The poor customer service from both Proven and the installers has been very frustrating. It became clear Proven had been swamped with orders due to government grants but had not expanded their workforce in response.
The intensity of shadow flicker the turbines produce was completely unexpected. The turbines project a strobe like flickering shadow into rooms to the north of the turbines for limited periods on sunny days. The most intolerant of this effect are the college library staff during the summer months.
The turbines cause the steel frame of the Innovation Centre to shudder during periods of strong wind. This is only a minor effect but a minority of occupiers found the effect disturbing. The complaints finally subsided by the end of 2007.
There have been no formal complaint regarding noise from either college users or surrounding neighbours.

2.11. Summary

2.11.1. Overall Energy Evaluation

	Predicted	Obtained	Predicted total	Obtained total
Wind turbine output	5kWh/m^{2}a	1.3kWh/m^{2}a	30000kWh/a	7264 kWh/a
Measured electricity consumption 2002			650000 kWh/a	
Turbine output predicted percentage of consumption			4.6%	
Actual percentage of consumption			1.1%	

2.11.2. Overall Economic Evaluation

Cost of turbines foreseen	Cost of turbines actual	Savings foreseen	Savings actual	Payback foreseen	Payback actual
€ 75000	€ 96424	€ 3000	€ 726	25 years	133 years

It is hoped the energy production will reach 10000 kWh/a now the turbines work properly although this would still produce an excessive payback period of 96 years.

2.12. Lessons Learned

2.12.1. Wind Turbines

- The most important issue, for those considering a wind turbine is to do a year of wind speed monitoring before making the decision to purchase. DO NOT rely on existing wind speed data bases. The key factor in the performance of the turbines at this College is the very low average wind speed of 2.8 m/s caused by the presence of the Tower Block.

- It is essential that a local installer is used who takes full legal responsibility for the units they supply. Problems will arise and a local supplier is much more likely to be responsive.
- The installer must be instructed to fully consider all design issues before starting work. Otherwise the risk of unforeseen expenditure increases greatly. The winching points at the college should not have needed re-design at a late stage in the project.
- An installer with proper experience of installing wind turbines is essential. This will mean taking up references before making an appointment. The college used their installer due to previous experience and their success at winning grants. But it was then discovered they had very limited experience of wind turbines.
- The effects of shadow flicker must not be underestimated. This is much more than moving shadows. It is a strobe lighting effect that is caused by the sunlight projecting through the moving turbine blades into adjacent parts of the building. This means predicting the route of turbine shadows through the year to assess and identify problem areas.
- Vibration has been an issue for the college. The Innovation Centre is a steel frame building but the dampening under the turbines' support structures is very basic. The designer was challenged to consider this more prior to installation but he stated it was somewhat experimental. The shuddering the building experiences only occurs during strong wind speeds. It is a minor shuddering but has caused some concern among occupants. Signs have been put up around the upper floor rooms explaining the vibration. This movement is less than would be induced by bus on tick-over next to the building or the vibration that can be caused by heavy trolleys.

- To erect turbines on existing building the original structure design must be available otherwise the structural investigations to establish suitability of the building would be cost prohibitive. It is presumed a reinforced concrete structure would transmit less vibration than a steel structure.
- The inverters to rectify the turbines' power output to the electrical supply of the building caused a power loss of up to 10%. This is made worse by time lag for the in-line inverters to become active when the power output trigger points are reached. What is worse, when

the turbines over generate, the inverters automatically tripout. The selection of the inverters and their programming needs to be carefully considered at the design stage.

- In windy weather the noise from the turbines is more significant because it can be experienced directly underneath the turbines adjacent to the building. The noise at worst, is like the cutting of the air, helicopter blades will produce although there is no loud engine noise. But when they are at their noisiest so are background noise levels due to the high wind conditions. No actual complaints have been received from users of the site, occupiers of the building or neighbours. Noise is not a problem.
- The local planning office was quite supportive so planning consent was easy to obtain although it had to include an environment impact assessment. Building Regulations Approval was straight forward. Installation was quick and easy although a proper Health and Safety risk assessment and method statement must be prepared.

2.12.2. General lessons learnt during the Tower Block design process.

- Untested opinions and ideas are critical to the creative process, however the modelling of these ideas are essential. Time needs to be built in to the programme to facilitate sufficient analysis and testing of ideas, particularly when dealing with the constraints offered by an existing building.
- It is important to establish a model of the building to allow the rapid testing of ideas, as the most obvious concepts do not always offer the greatest benefit. For example the proposed vertical brise soliel under the PV array to the west elevation. Modelling showed a good saving from solar gain but the additional cost was unacceptable to the client
- The long payback period discourages the choice of low energy technologies unless grant funding is available to support investment.
- Alternative and more adventurous solutions should always be considered as they can have positive benefits if properly researched, proved and implemented.
- It is possible to integrate technologies to serve dual purposes. In the case of this building the PV arrays would also serve as solar shading. Careful consideration of all aspects of a project at the outset will permit such integration.
- The goal for all designers is that the services concepts should always start from a desire to consume zero energy and only add what is required to make the building function. It is not acceptable to use established benchmarks as a starting point as this can stifle innovation and lead to tried and tested solutions coming to the fore. This should apply to all projects and not just those seeking to be specifically energy saving.
- Better control of services can save considerable quantities of energy. This should be coupled with high quality commissioning procedures and concise training of the Client in the best use of the systems. Poorly trained people will not use systems effectively and energy consumption will suffer as a result.
- The introduction of thorough sub-metering linked to the BMS is essential to allow for efficient management of utilities. There is an education process required at the handover stage to ensure that building users understand the advantages and/or limitations of any installed systems.
- There may be an expectation that the systems will perform functions or provide results that are outside of design parameters. This needs to be clearly explained such that the end users are "bought in" to the processes at an early stage. Close liaison with the Client and end users through the design process is a great advantage.
- Many low energy technologies are currently produced by small businesses. These businesses struggle to provide good customer service when experiencing high demand. The use of businesses within the same region as the development is recommended.

Appendix A – separate document

Plymouth Wind Turbine

Data Analysis

GDL-TN-2007-11

December 2007

GasDynamics

2 Clockhouse Road
Farnborough
GU14 7QY
www.gasdynamics.co.uk

Report Issue Sheet

Title:	Plymouth Wind Turbine Data analysis
Number:	GDL-TN-2007-11
Revision:	Revision 0
Date of Issue:	14th December 2007
Prepared by:	C. Walton
Reviewed by:	M. Zanchetta

Table of Contents

1 Introduction

1.1.1 This report has been prepared by Gas Dynamics Limited for Photon Energy Ltd under PO 00068-JB-I1000 entitled “Data analysis & reporting of CCP turbine output”. The report describes the monthly wind rose and power curve, derived from data collected by a 6kW Proven turbine at City College, Plymouth.

2 March data analysis

2.1.1 Figure 2.1 below shows the wind speed as a function of time plotted directly from the data file. There are peaks in wind speed of just under 15m/s on the 05th March, with the average wind speed for the month from all directions being 3.15m/s. The overall yield from the turbine in the month is 318kWh representing a capacity factor of 7.12%.

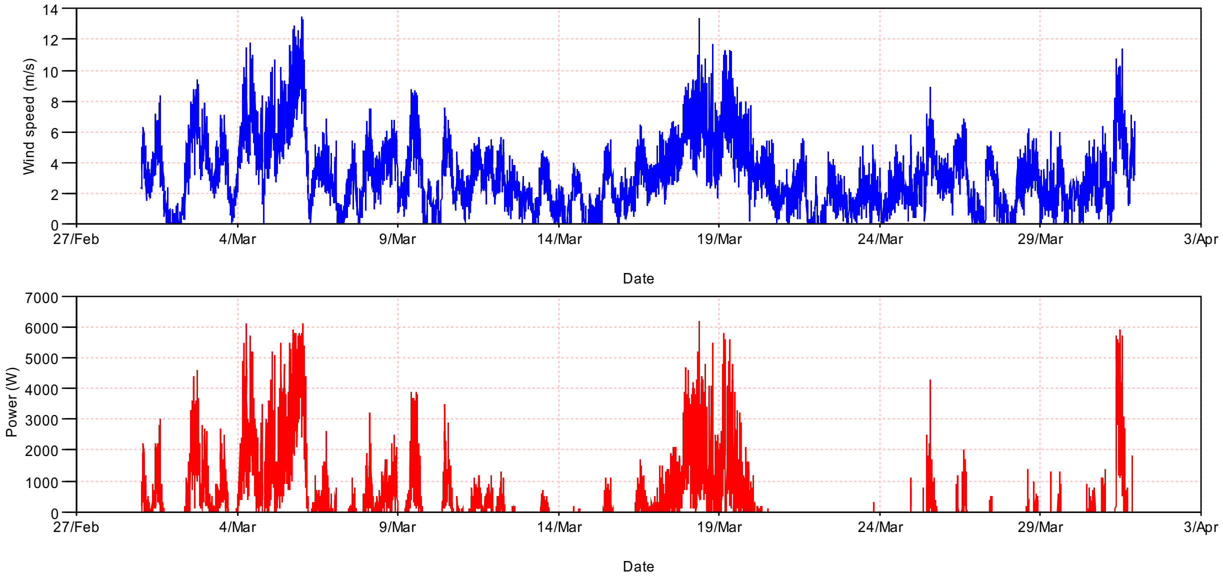


Figure 2.1; Wind speed and power as a function of time from the raw data file during March.

2.1.2 The distribution of wind speed by direction interval (a wind rose) is shown in figure 2.2 below. The plot shows the frequency of the wind by direction interval and by wind speed interval using the one minute average readings. The prevailing wind is predominantly from a North Westerly direction which is a little unusual for the UK [although a quick look at wind atlas data for both Exeter and Burrington (Devon) shows a similar trend]. If there is a weather station close to the site, it would be worth obtaining both the near term and long term wind data and comparing this with the monthly and yearly wind speed measurements from the turbine.

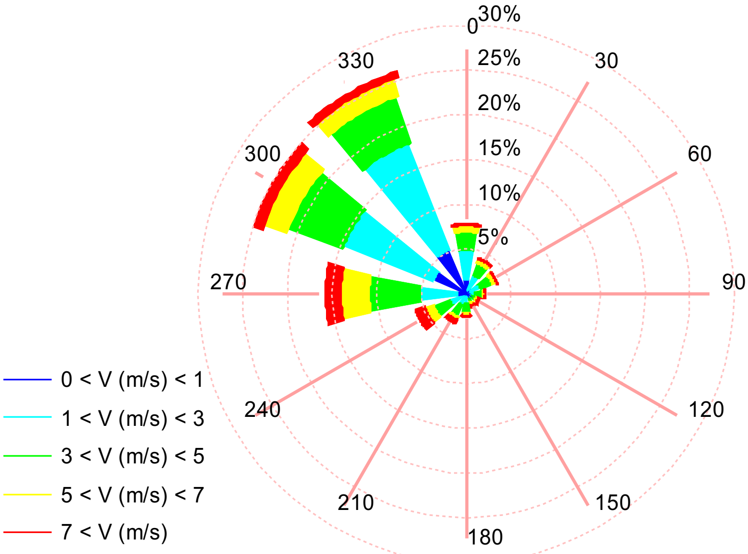


Figure 2.2; Wind rose for March. North is denoted by 0°.

2.1.3 The final plot shown in figure 2.3 is the power curve generated from March's data. The black dots represent the one minute average readings (they appear as lines due to the 0.1m/s resolution of the anemometer), the blue line is the mean power curve, and the red curves represent the standard deviation from the mean. The curve is unreliable at wind speeds above 11m/s due to the lack of available data points.

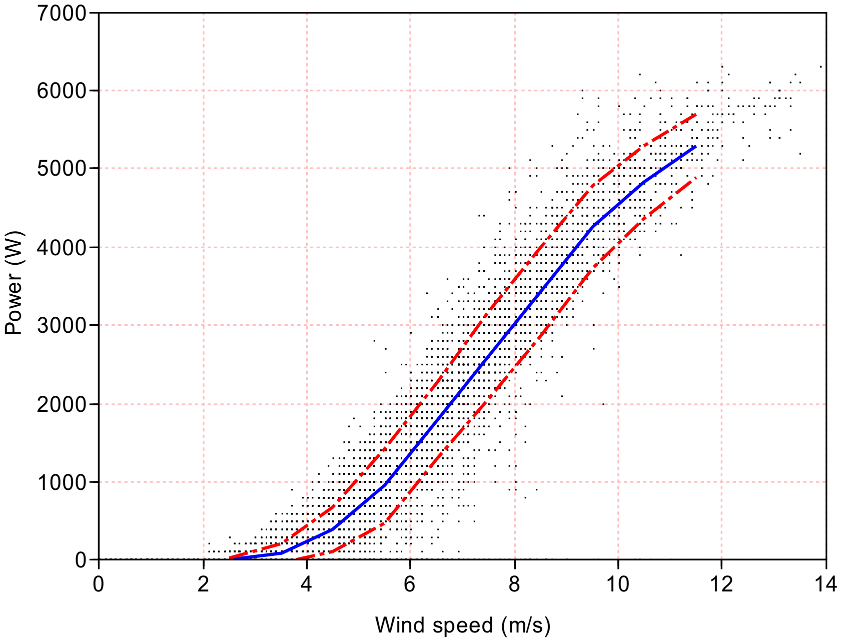


Figure 2.3; Power curve from March's data; The black dots are the one minute average readings; the blue curve is the mean power curve; and the red curve is the standard deviation.

3 April data analysis

3.1.1 Figure 3.1 below shows the wind speed and power as a function of time plotted directly from the data file. There appears to have been a problem with the turbine during the month as there are periods where no power is recorded even though there are significant wind speed levels. There are peaks in wind speed of just over 11m/s on the 02nd April, with the average wind speed for the month from all directions being 2.36m/s.

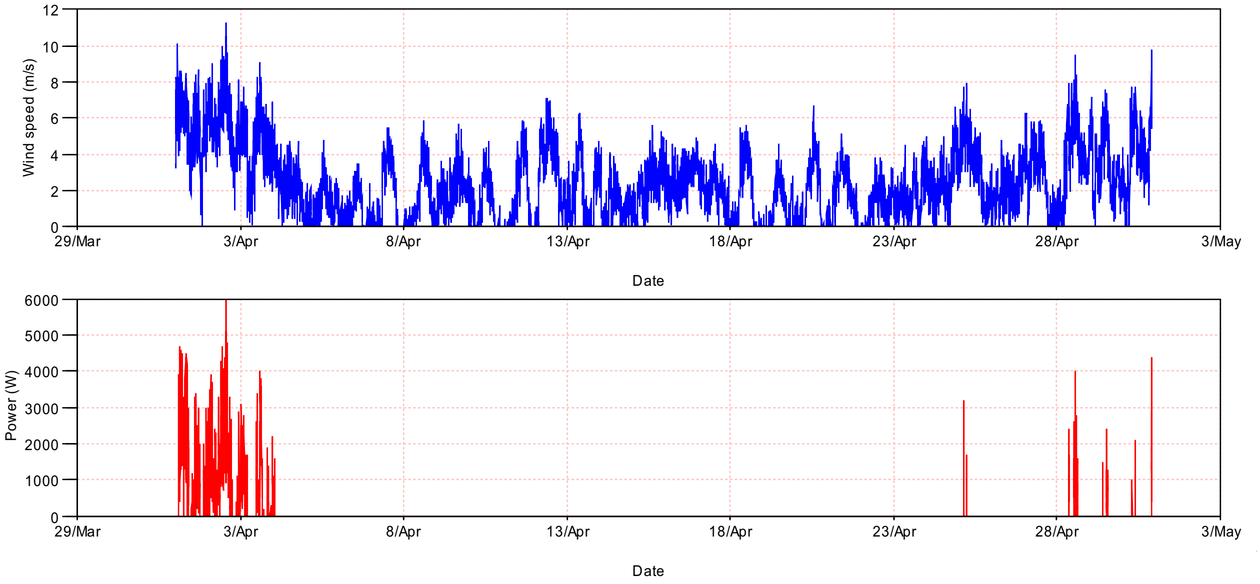


Figure 3.1; Wind speed and power as a function of time from the raw data file during April.

3.1.2 The distribution of wind speed by direction interval (a wind rose) is shown in figure 3.2 below.

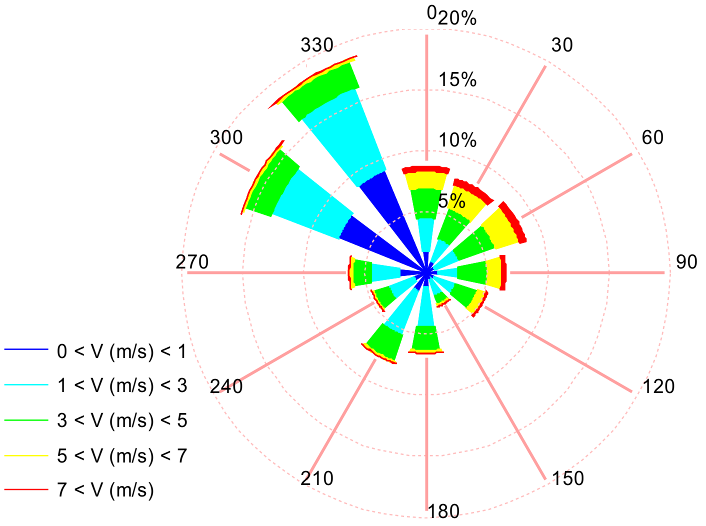


Figure 3.2; Wind rose for April. North is denoted by 0°.

4 May data analysis

4.1.1 Figure 4.1 below shows the wind speed as a function of time plotted directly from the data file. There are peaks in wind speed of just over 11m/s on the 01st May, with the average wind speed for the month from all directions being 3.44m/s. The overall yield from the turbine in the month is 310kWh representing a capacity factor of 6.9%.

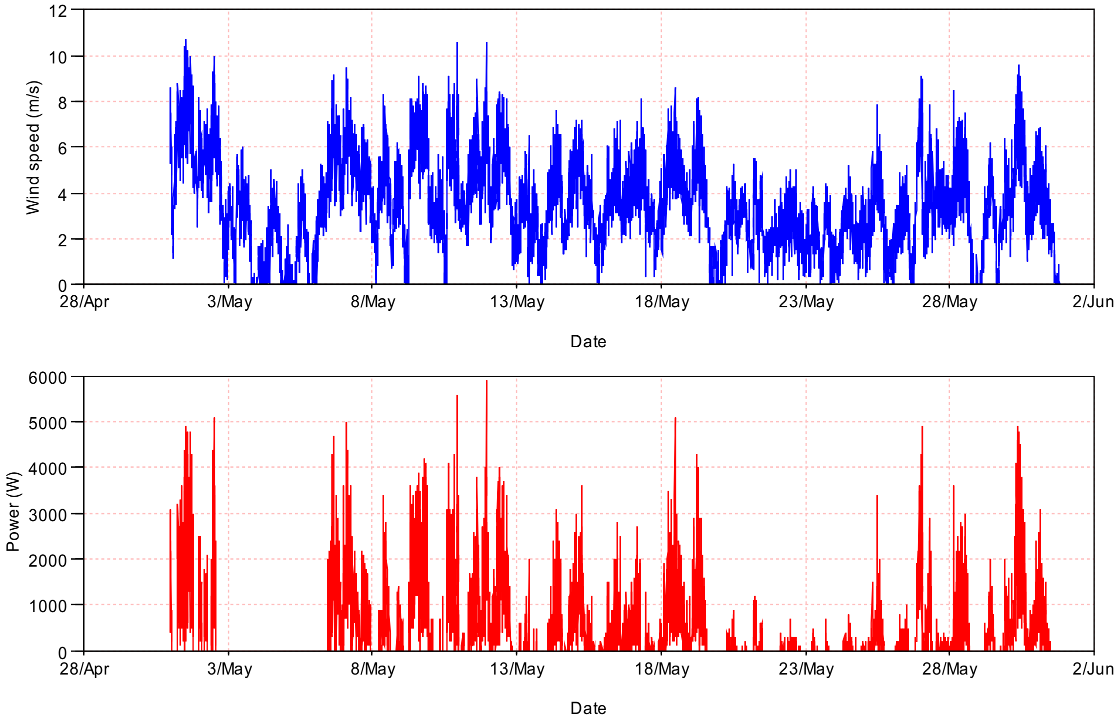


Figure 4.1; Wind speed and power as a function of time from the raw data file during May.

4.1.2 The distribution of wind speed by direction interval (a wind rose) is shown in figure 4.2 below. The plot shows the frequency of the wind by direction interval and by wind speed interval using the one minute average readings. The prevailing wind is predominantly from a Westerly direction, although there are also significant contributions in the 240° and 300° intervals. Note that there are almost no significant wind speed measurements heading from North to South in a clockwise direction.

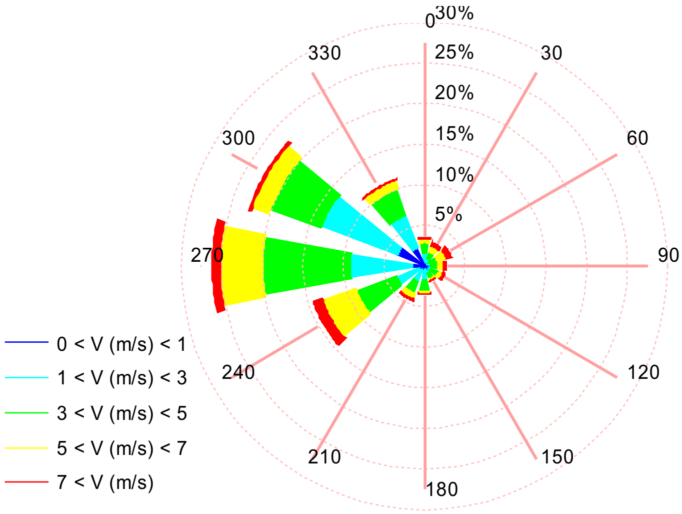


Figure 2.2; Wind rose for May. North is denoted by 0°.

4.1.3 The final plot shown in figure 2.3 is the power curve generated from May's data. The black dots represent the one minute average readings, the blue line is the mean power curve, and the red curves represent the standard deviation from the mean. The curve is unreliable at wind speeds above 8.5m/s due to the lack of available data points.

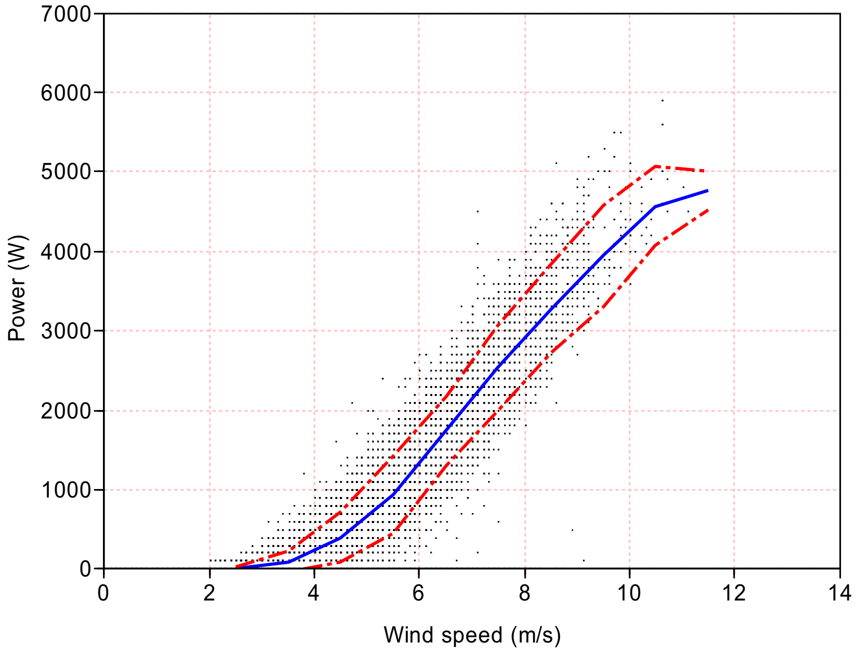


Figure 4.3; Power curve from May's data; The black dots are the one minute average readings; the blue curve is the mean power curve; and the red curve is the standard deviation.

5 June data analysis

5.1.1 Figure 5.1 below shows the wind speed as a function of time plotted directly from the data file. There are peaks in wind speed of just 10.5m/s on the 20th June, with the average wind speed for the month from all directions being 2.73m/s. The overall yield from the turbine in the month is 212kWh representing a capacity factor of 4.90%. Similar to April there is a period from about 06th to 13th June where no power is recorded even though there are significant wind speed levels.

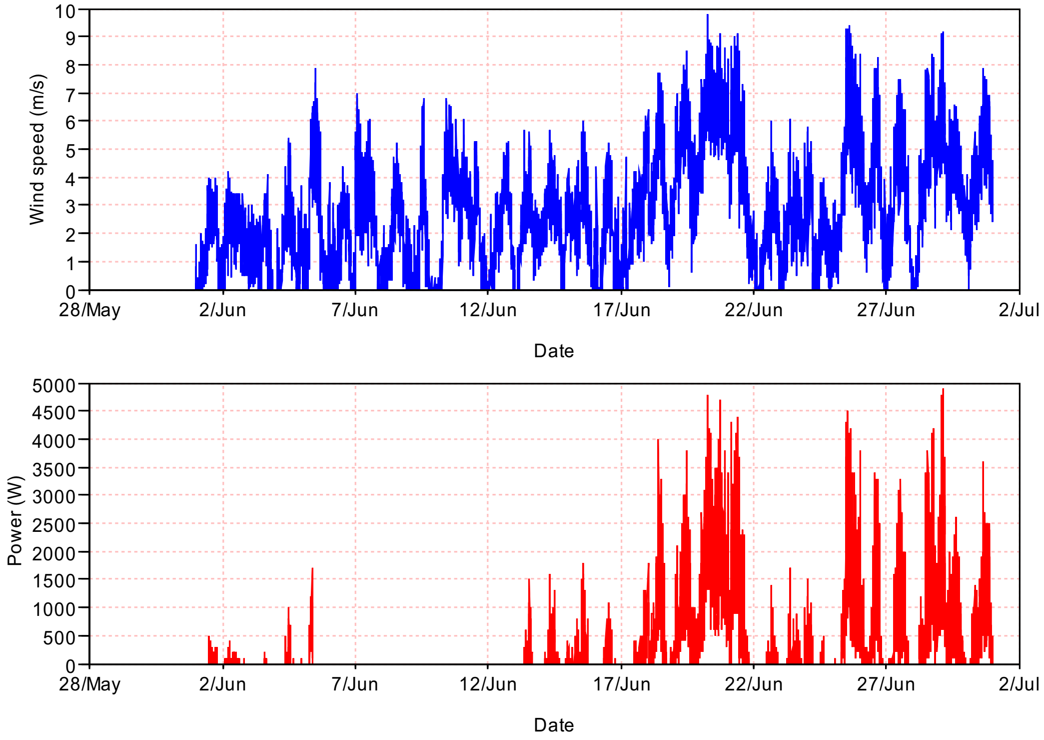


Figure 5.1; Wind speed and power as a function of time from the raw data file during June.

5.1.2 The distribution of wind speed by direction interval (a wind rose) is shown in figure 2.2 below.

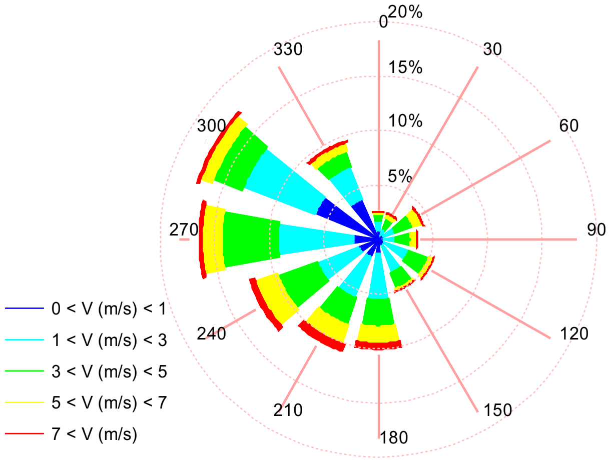


Figure 5.2; Wind rose for June's data.

6 July data analysis

6.1.1 Figure 6.1 below shows the wind speed as a function of time plotted directly from the data file. There are peaks in wind speed of just over 10m/s on the 26th July, with the average wind speed for the month from all directions being 3.2m/s. The overall yield from the turbine in the month is 324kWh representing a capacity factor of 7.25%.

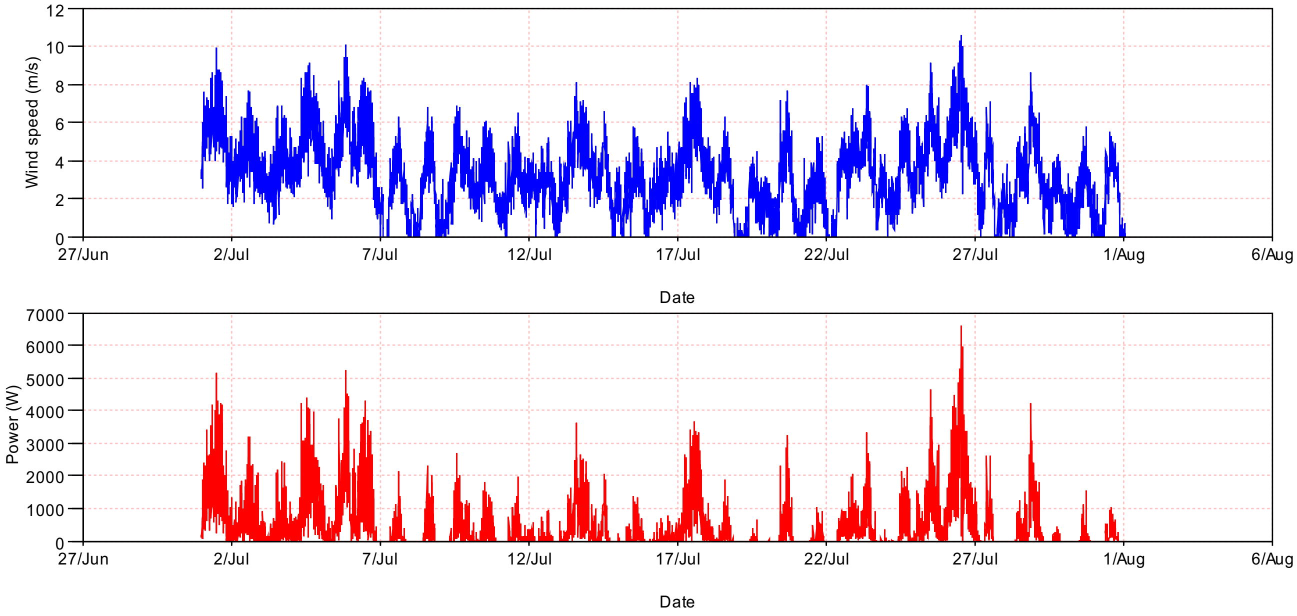


Figure 6.1; Wind speed and power as a function of time from the raw data file during July.

6.1.2 The distribution of wind speed by direction interval (a wind rose) is shown in figure 6.2 below. The plot shows the frequency of the wind by direction interval and by wind speed interval using the one minute average readings. The prevailing wind is predominantly from a Westerly direction, although there are also significant contributions in the 240° and 300° intervals. Note that there are almost no significant wind speed measurements heading from North to South in a clockwise direction.

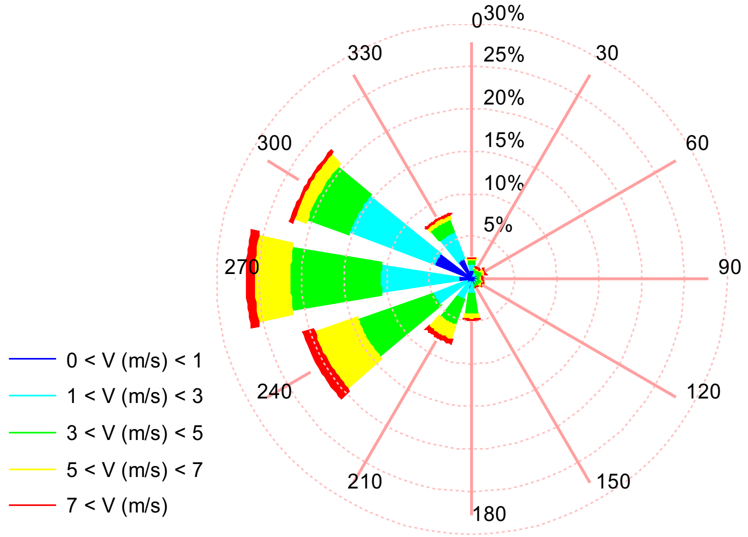


Figure 6.2; Wind rose for July. North is denoted by 0°.

6.1.3 The final plot shown in figure 6.3 is the power curve generated from July's data. The black dots represent the one minute average readings (they appear as lines due to the 0.1m/s resolution of the anemometer), the blue line is the mean power curve, and the red curves represent the standard deviation from the mean. The curve is unreliable at wind speeds above 8.5m/s due to the lack of available data points.

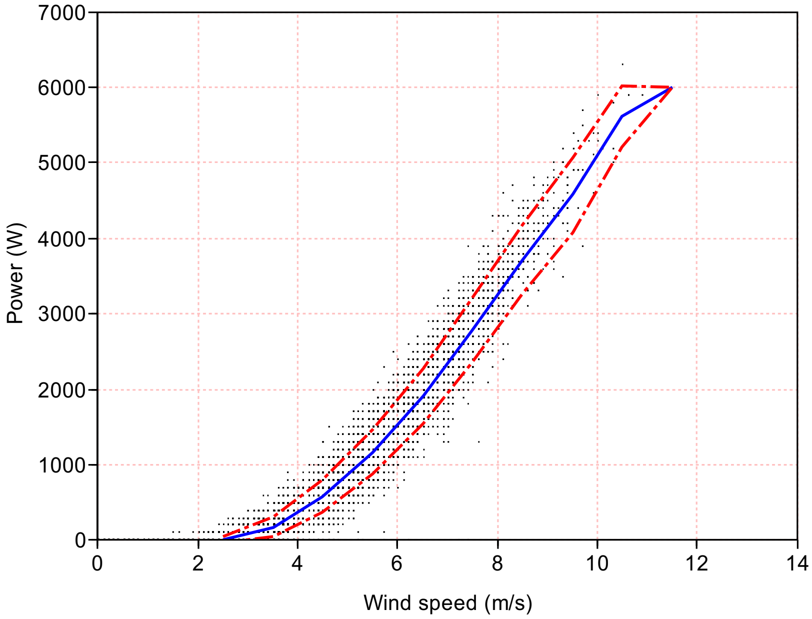


Figure 6.3; Power curve from July's data; The black dots are the one minute average readings; the blue curve is the mean power curve; and the red curve is the standard deviation.

7 August data analysis

7.1.1 Figure 7.1 below shows the wind speed as a function of time plotted directly from the data file. There are peaks in wind speed of just over 9.5m/s on the 13th August, but the overall wind speed levels are generally quite low, with the average wind speed for the month from all directions being 2.6m/s. As a result the overall yield from the turbine in the month is just 142kWh representing a capacity factor of 3.2%.

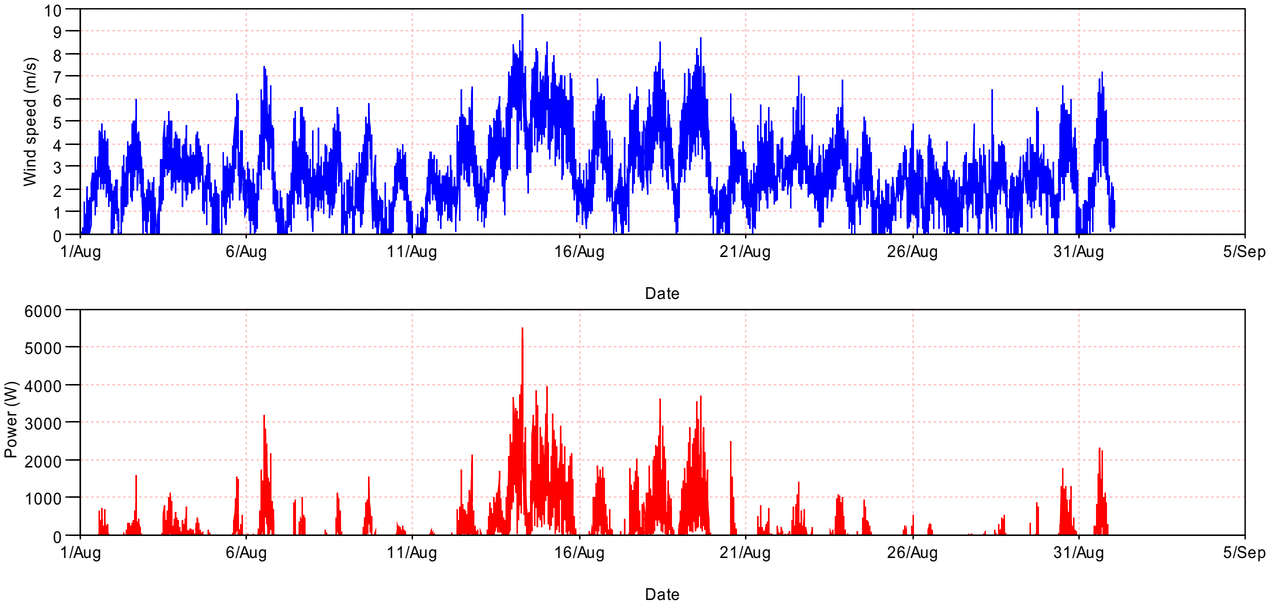


Figure 7.1; Wind speed as a function of time from the raw data file during August.

7.1.2 The distribution of wind speed by direction interval (a wind rose) is shown in figure 7.2 below. The plot shows the frequency of the wind by direction interval and by wind speed interval using the one minute average readings. The prevailing wind is predominantly from a North Westerly direction which is a little unusual for the UK [although a quick look at wind atlas data for both Exeter and Burrington (Devon) shows a similar trend]. If there is a weather station close to the site, it would be worth obtaining both the near term and long term wind data and comparing this with the monthly and yearly wind speed measurements from the turbine.

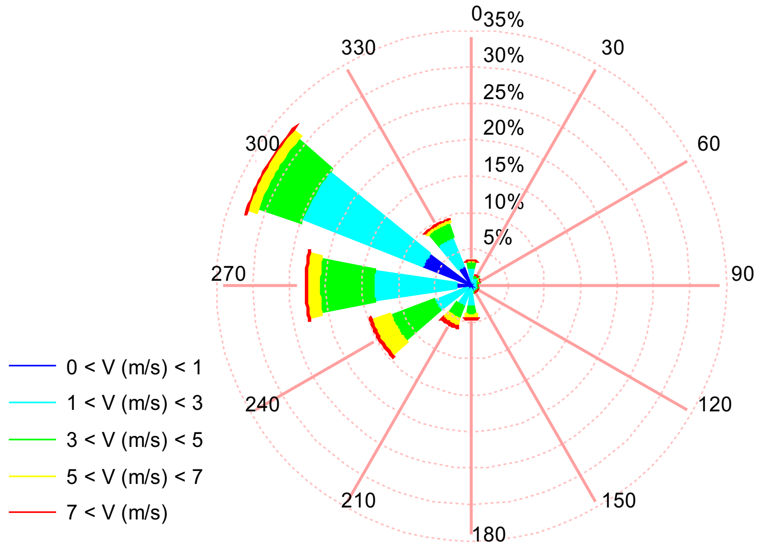


Figure 7.2; Wind rose for August. North is denoted by 0°.

7.1.3 The final plot shown in figure 7.3 is the power curve generated from August's data. Again, the curve is unreliable at wind speeds above 8.5m/s due to the lack of available data points.

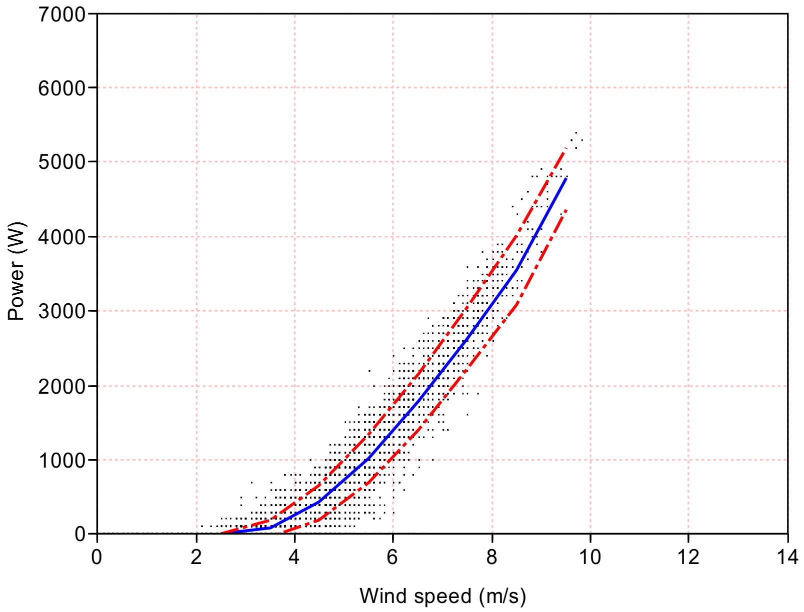


Figure 7.3; Power curve from August's data; The black dots are the one minute average readings; the blue curve is the mean power curve; and the red curve is the standard deviation.

8 September data analysis

8.1.1 Figure 8.1 below shows the wind speed as a function of time plotted directly from the data file. There is a peak in wind speed of 12.8m/s on the 24th September, but the overall wind speed levels are low, with the average wind speed for the month from all directions being 2.2m/s. As a result the overall yield from the turbine in the month is just 130kWh representing a capacity factor of 3%.

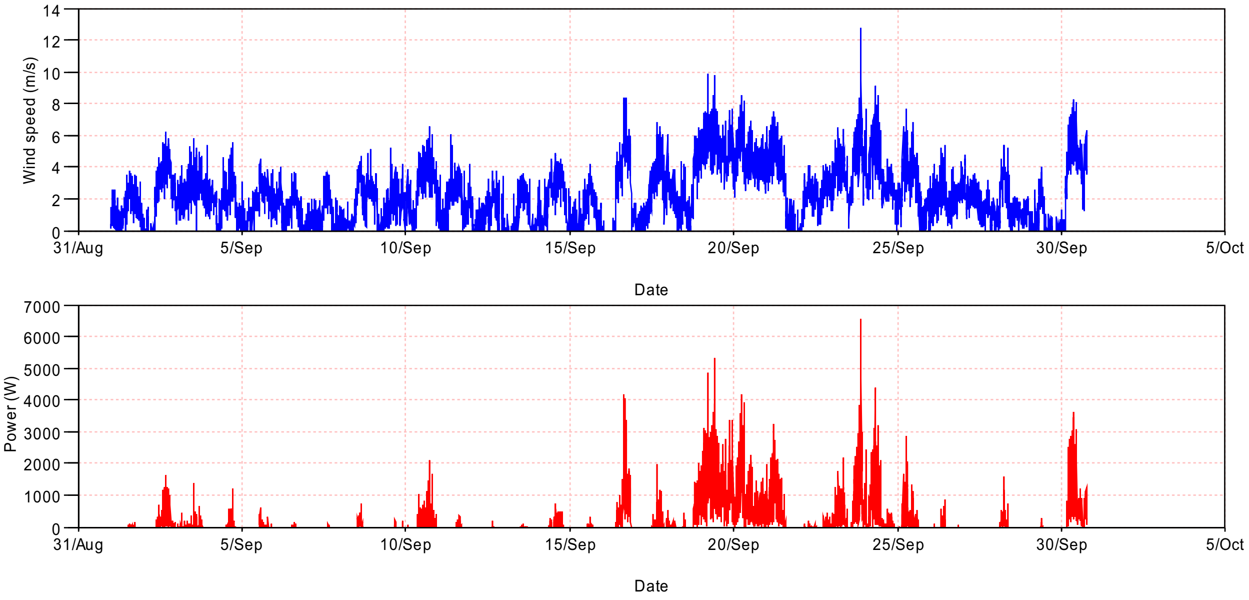


Figure 8.1; Wind speed as a function of time from the raw data file during September.

8.1.2 The distribution of wind speed by direction interval is shown in figure 8.2 below. As with August the wind is predominantly from a North-Westerly direction.

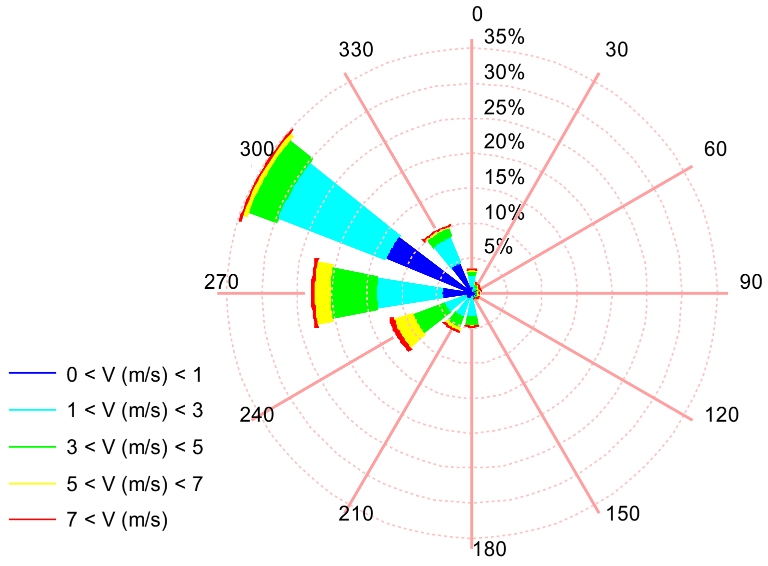


Figure 8.2; Wind rose for September

8.1.3 The final plot shown in figure 8.3 is the power curve generated from September's data. Again, the curve is unreliable at wind speeds above 7m/s due to the lack of available data points.

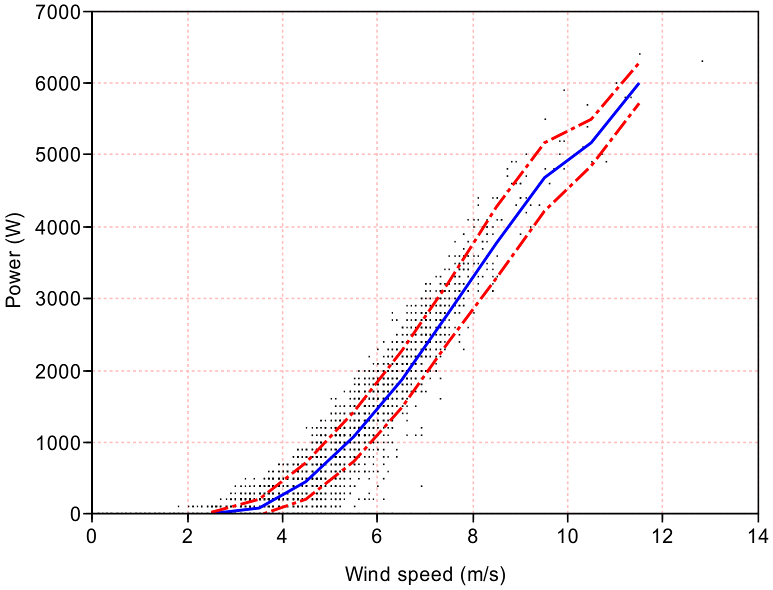


Figure 8.3; Power curve from September's data; The black dots are the one minute average readings; the blue curve is the mean power curve; and the red curve is the standard deviation.

9 October data analysis

9.1.1 Figure 9.1 below shows the wind speed as a function of time plotted directly from the data file. There is a peak in wind speed of 10.1m/s on the 28th October, but the overall wind speed levels are very low, with the average wind speed for the month from all directions being 2.05m/s. As a result the overall yield from the turbine in the month is just 132kWh representing a capacity factor of 3%.

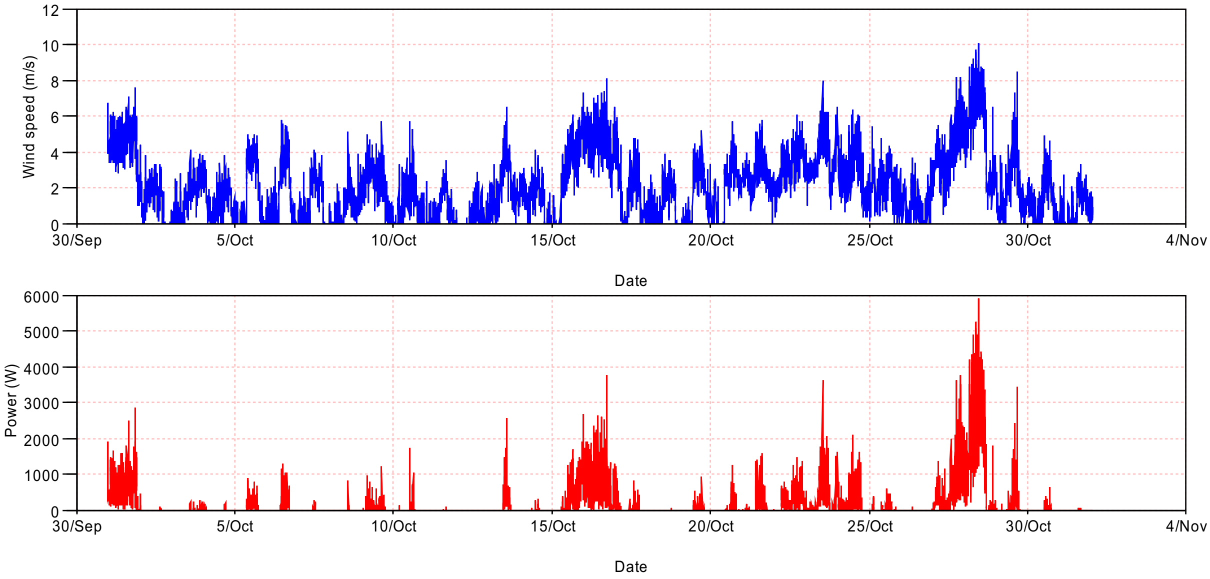


Figure 9.1; Wind speed as a function of time from the raw data file during October.

9.1.2 The distribution of wind speed by direction interval is shown in figure 9.2 below. Unlike the preceding months there is a significant component of wind in the direction interval between 0° and 120°.

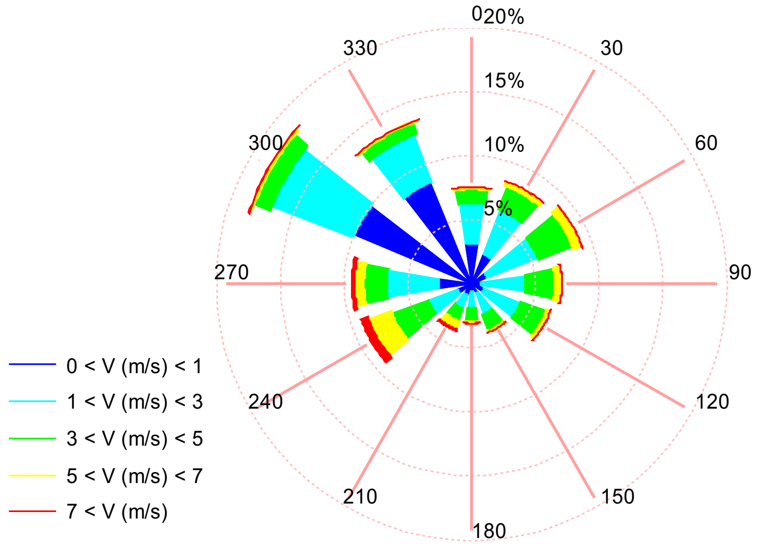


Figure 9.2; Wind rose for October.

9.1.3 The final plot shown in figure 9.3 is the power curve generated from October's data. Again, the curve is unreliable at wind speeds above 7m/s due to the lack of available data points.

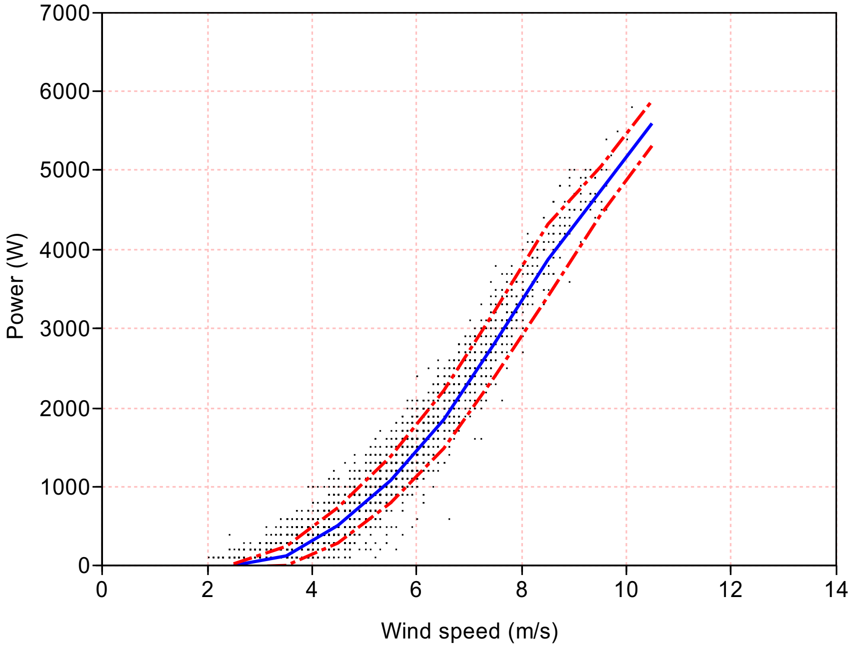


Figure 9.3; Power curve from October's data; The black dots are the one minute average readings; the blue curve is the mean power curve; and the red curve is the standard deviation.

10 November data analysis

10.1.1 Figure 10.1 below shows the wind speed as a function of time plotted directly from the data file. There is a peak in wind speed of 12.4m/s on the 30th November, but the overall wind speed levels are very low, with the average wind speed for the month from all directions being 1.93m/s. As a result the overall yield from the turbine in the month is just 138kWh representing a capacity factor of 3.2%.

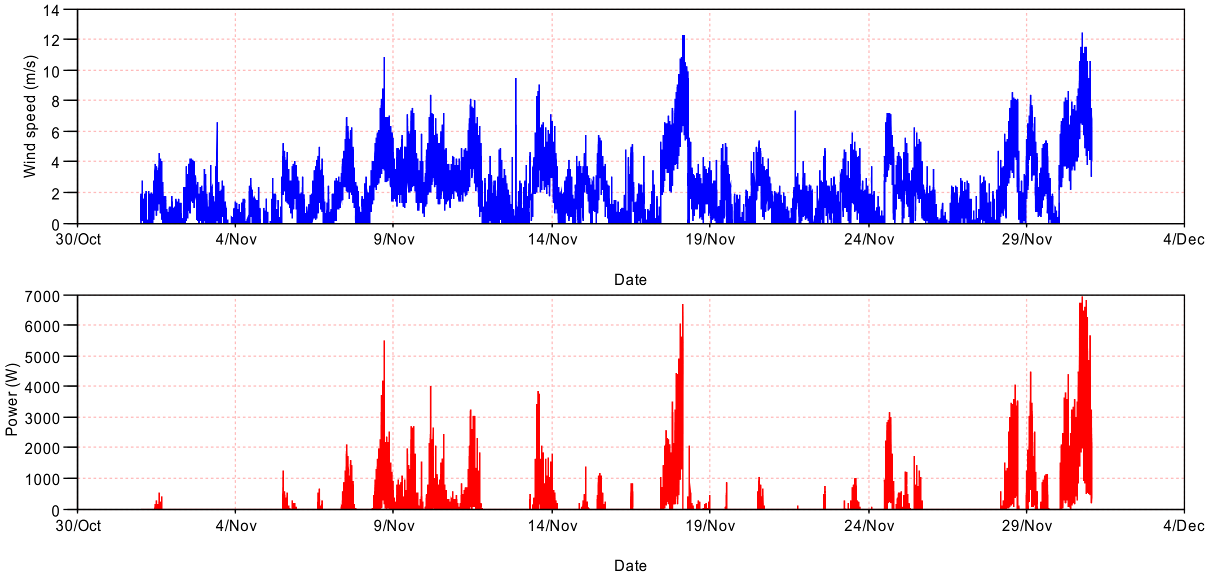


Figure 10.1; Wind speed as a function of time from the raw data file during November.

10.1.2 The distribution of wind speed by direction interval is shown in figure 10.2 below. As with August the wind is predominantly from a North-Westerly direction.

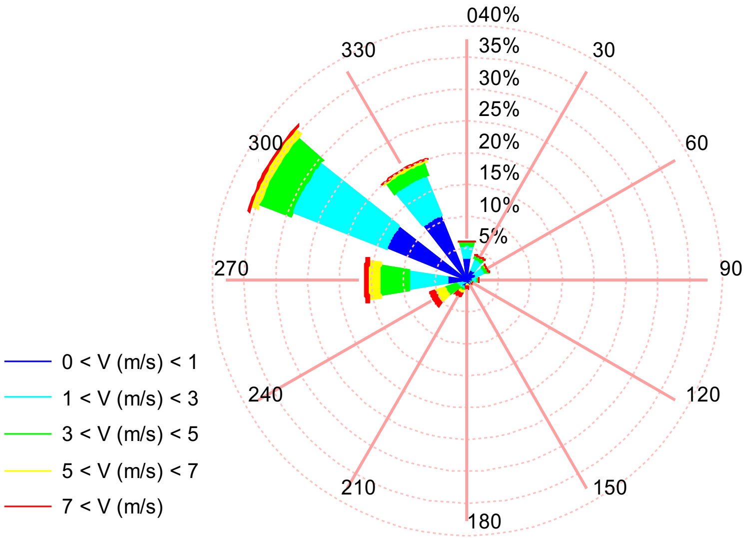


Figure 10.2; Wind rose for November.

10.1.3 The final plot shown in figure 10.3 is the power curve generated from November's data.

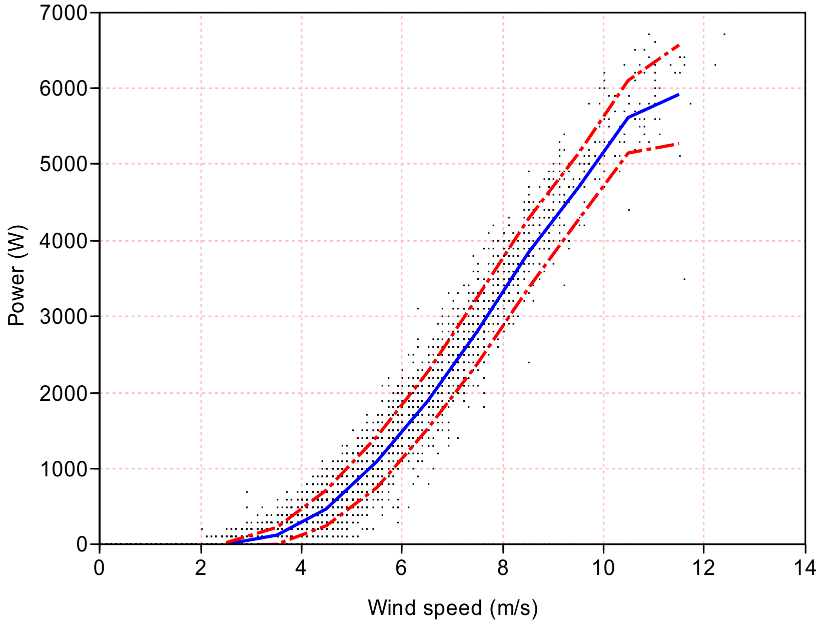


Figure 10.3; Power curve from November's data; The black dots are the one minute average readings; the blue curve is the mean power curve; and the red curve is the standard deviation.

11 December data analysis

11.1.1 Figure 11.1 below shows the wind speed as a function of time plotted directly from the data file. There is a peak in wind speed of 15.8m/s on the 02nd December, with the average wind speed for the month from all directions being 4.21m/s. The overall yield from the turbine in the month is 745kWh representing a capacity factor of 16.7%.

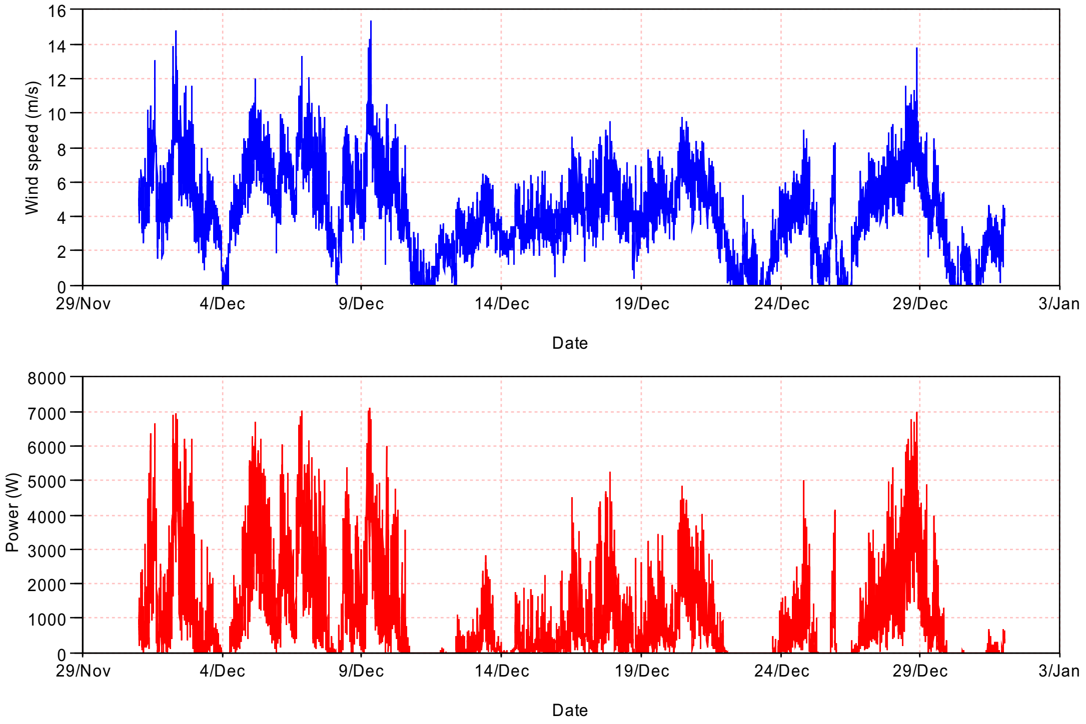


Figure 11.1; Wind speed as a function of time from the raw data file during December.

11.1.2 The distribution of wind speed by direction interval is shown in figure 11.2 below.

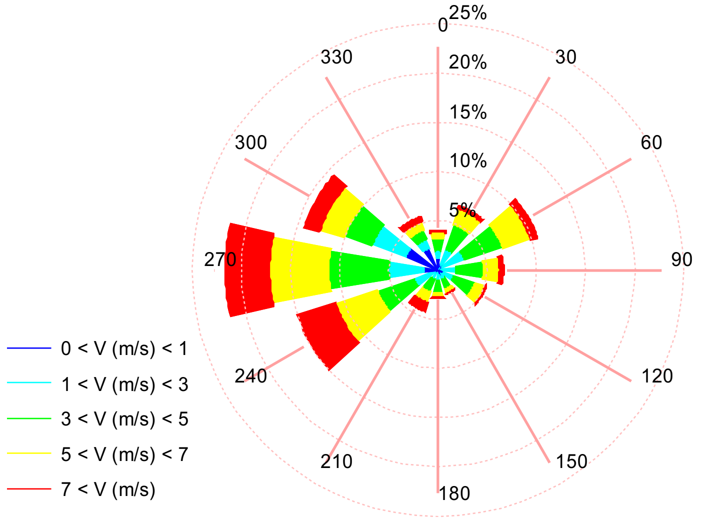


Figure 11.2; Wind rose for December.

11.1.3 The final plot shown in figure 11.3 is the power curve generated from December's data. There are sufficient data points in December to extend the power curve to 11m/s.

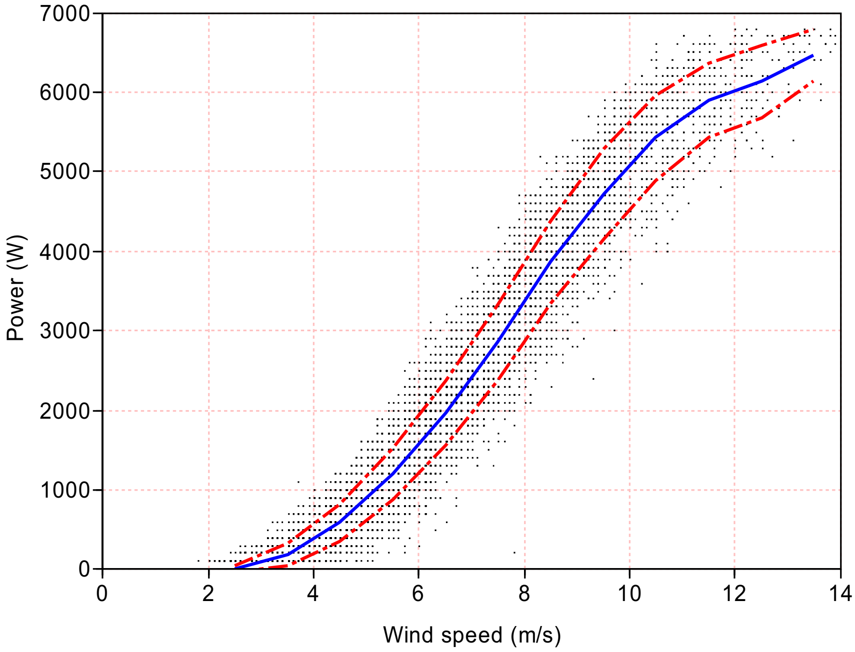


Figure 11.3; Power curve from December's data; The black dots are the one minute average readings; the blue curve is the mean power curve; and the red curve is the standard deviation.

3. Borgen Community Centre

Author: Jan Rolland

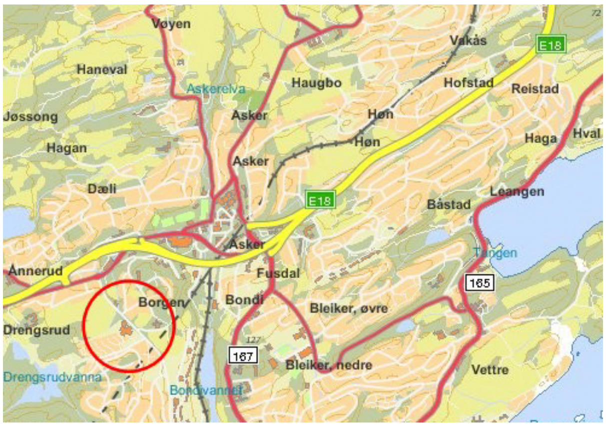
3.1. General data

3.1.1. General information

Year of construction:	1971
Year of renovation (start):	2002 (initial planning)
Number of storeys:	1 (+ technical basement and small mezzanine)
Heated volume	42236 m^3
Cubic contents, volume	35558 m^3
Gross area	10178 m^2
Living area	9049 m^2
Window/glass areas (m^2):	750/398 (skylight)

3.1.2. Site

Borgen Community Centre is located in an open suburban area approximately 2 kms from the centre of Asker, which is situated 20 kms southwest of Oslo, the capitol of Norway. The location is 59˚50´ northern latitude and 10˚25´ eastern longitude. Altitude is 164 meters above sea level. The climate is typical for inland areas in southern Norway. Normal summer temperatures range from 15 to 28˚C, while winter temperatures range between +5 and -20˚C. Average precipitation is 1100 to 1200 mm per year. Snow depth varies from 20 to 80 cm.



3.1.3. Building type

Local Community Centre containing 5 parallel secondary school, kindergarten, youth activity center, health care, dental services and rooms dedicated to private organizations.

3.2. Before retrofit

3.2.1. Building construction

Prefab concrete pillars and beams carrying a roof structure of U-shaped insulated concrete elements. The building had concrete foundations secured to underlying rock and concrete slab floors with vinyl covering. Outer walls were made with 4” wood framework and brick cladding. Wooden windows had standard double-glazing. Internal walls were also made with wood framework and plasterboards on both sides.

Old school with large shed roofs that reduced daylight through windows

3.2.2. Existing heating, ventilation, cooling, lighting systems

The building had electric heating with resistance heaters underneath the windows. Ventilation was based on a decentralized system with five ventilation units placed on the roof above each of the main building sections. Fresh air was filtered and preheated with electric heaters before it was distributed to the building. Used air went through a heat recovery system before it was exhausted. The units had low capacity and efficiency, and there was no cooling.

3.2.3. Energy and water use

Practically all energy used in the building was based on electric power. In Norway almost 90% of electric power is produced in hydroelectric power plants, and therefore represent an environment friendly and renewable energy source. Water saving measures was not and issue in the project. The school and health centre have normal water consumption and there would not be need for special initiatives. The gymnasium located in the adjacent dodecahedron building had already installed water saving showers, and the retrofit only applied to upgrading the facades, changing windows and doors and improving insulation.

	Measured year	**Total for the whole building**
Electricity	280 kWh/m^2 a	1.120.000 kWh/a
DHW (included)	-	-
Space heating (included)	-	-
Water	na	na

3.2.4. User satisfaction before retrofit

There had been no comfort studies among teachers and students, but over the years there had been a number of complaints concerning the building facilities in general and the indoor climate in particular. The building was cold during winter and hot in the summer. Ventilation was inadequate and many had problems with headaches at the end of the day. The state of the building was poor with insufficient insulation and facades marked by 30 years of decay. Technical installations were also ready for replacement. This was reported to the principle who in turn brought the concern to the politicians. Around the turn of the century this lead to the decision that the school should be replaced.

3.3. Energy saving concept

The overall goal for the retrofit was:

- Reduce total energy consumption by 50% or better
- Create a good indoor climate with low energy consumption with respect to heating, ventilation and lighting.
- Optimise use of space with flexible plans that allow new pedagogical working methods as well as integrating local community activities

The building was generally in poor condition with insufficient insulation, air leakages in both windows and walls and extensive damages on brick cladding. The roof elements did not meet new requirements to snow loads and needed to be replaced. This would enable opening roof areas to let daylight into the dark central areas of the building and also increase roof insulation. The main structure had to be strengthened with steel trusses. Rehabilitation of the walls would be more expensive than replacing them with completely new walls. Windows area could then easily be increased as well as insulation thickness.

3.3.1. Building construction

	Pre retrofit Uvalue [w/m^2]	Post retrofit Uvalue [w/m^2]
Walls	0,35	0,2
Roof	0,6	0,13
Windows	2,0	1,1
Floor	0,3	0,15

3.3.2. Heating

Since electric power in Norway is a clean and renewable energy resource, it was natural to base energy consumption on electricity. To optimise the use of electricity for room heating, a geothermal heat pump was chosen. It produces about 2,5 to 3 times more heat than the electricity used to run the heat pump. Heat is pumped from the ground from energy wells. During the summer it can provide cooling by pumping excess heat back into the ground and thus “recharging” the wells. A 150 m deep test well was drilled to map potential capacity, and calculations were made to estimate expected payback time. Depending on the interest rate and electric energy prices, payback time was calculated to somewhere between 10 and 13 years.

3.3.3. Ventilation

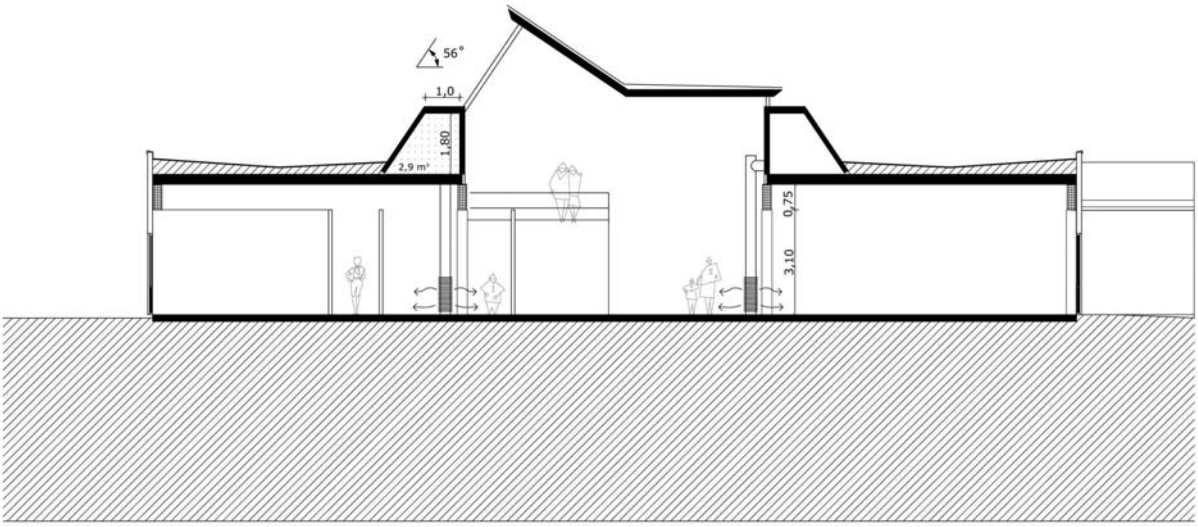
To reduce running costs for ventilation, a natural hybrid ventilation system was chosen. By, to a large extent, using natural driving forces, buoyancy and wind, the need for electric power to run ventilation fans is greatly reduced. Fresh air is brought into the building through air towers and underground concrete culverts. The culverts have a large volume that reduces air speed and allows distribution of fresh air with relatively low temperature and close to the user without feeling a draught. Airflow is regulated individually in each room by sensors for temperature, CO2 and motion and therefore adjusted to actual needs.

3.3.4. Cooling

Excess heat is often a problem in schools due to human generated heat and extensive use of computers, electric lighting and other heat generating equipment. For traditional ventilation systems without active cooling, this represents a problem. Fresh air is supplied at relatively high speeds that require higher temperatures to avoid sensation of draught. This in turn leads to high evacuation temperatures, and active cooling is often needed to keep temperature at an acceptable comfort level. Cooling is expensive and it was decided to aim at passive systems. The ground temperature cools the ventilation culverts and their massive concrete construction supplies enough thermal mass to even out temperature changes during the day. Ventilation can be run automatically during the night to cool the building when this is needed. The use of building materials with high thermal capacity then helps to keep the temperature throughout the day. The lower fresh air temperature also helps keeping room temperature at the recommended 20 - 21°C.

3.3.5. Lighting systems

The shape of the building made it necessary to improve daylight conditions, and SINTEF was engaged to make a study of the possibilities and effects from the suggested solutions. A model was built of the central area and a typical base area. These were then tested in the sun laboratory at the university in Trondheim. Tiny light sensors were placed in the models to measure the amount of light entering the building through the suggested windows and skylights. Results were positive. The large skylight facing north at an angle that would not let direct sunlight and heat into the building would very much increase the level of daylight in the central area. The narrow window facing south would also contribute without letting in much heat. The result was the same in the base area, but shutters had to be used to prevent unwanted heat.



Studies have shown that daylight is good for the human health and should be used more actively than the case is today for many buildings. In addition, it reduces costs for electric lighting and makes buildings more agreeable places to be. To optimise the effect of daylight, all artificial lights are adjustable and regulated by light sensors. In addition, light is also regulated by motion sensors that will turn the light on when someone enters the room, if conditions require so. When a room is left empty, the light will automatically be turned off after a preset time elapse. The IR-sensors also serve as detectors for the burglar alarm.

3.3.6. BEMS

Ensi AS (later changed name to EvoTek) was engaged as a special consultant to help us make specifications for the BEMS system and to follow up installation, programming and test runs. With such a large number of sensors, meters, electric valves, shutters, pumps etc, it was extremely important that all units could communicate properly. All installations had to operate with open protocols and Evo Tek ensured full compatibility. After tenders had been evaluated, Satchwell was chosen for BEMS contract.

3.3.7. Predicted energy savings

Energy saving measures	[kWh/m^{2}a]	Total [kWh/a]
Space heating	29	262420
Heating ventilation air	20	180980
Water heating	13	117635
Fans and pumps	15	135735
Lighting	23	208125
Equipment	11	99540
Total energy consumption	**111**	**1004435**
Total energy savings	**169**	**1074600***

*To get a fair comparison the new extension is kept out of the calculation.

3.3.8. Predicted costs and payback

Energy saving measure/investment	Area [m²]	Total costs [EUR]	Saving [EUR/a]	Pay-back periods [a]
Heat pump including energy wells, heat collectors, pipelines, trenches, planning and project management	5970	475000		
Natural hybrid ventilation including specially developed ventilation elements, CO2 regulation, heat recovery systems, planning and project management	5970	540000		
Total	**5970**	**1015000**	**100893**	**10,1**

Energy costs used for the payback calculation:
Electric/oil: 0,1 EURO/kWh (0,8 NOK/kWh)

3.4. Life Cycle Assessment

The main objective was to turn the building into a modern local community centre with emphasis on environment and energy. Natural/hybrid ventilation has replaced the old traditional ventilation. Daylighiting has been improved and energy saving lamps installed; pipes and ducts have been replaced. A geothermal heat pump has replaced the old electric resistance heaters.
Note: employed masses refer both to retrofit and to the construction of new building parts.

Measured yearly Energy Saving		
Space heating (heat)	277.632	[kWh/year]
Heating ventilation air (heat)	191.470	[kWh/year]
Water heating (heat)	124.456	[kWh/year]
Fans and pumps (Electricity)	143.603	[kWh/year]
Lighting (Electricity)	220.191	[kWh/year]
Equipment (Electricity)	105.309	[kWh/year]

Primary energy saving and emissions			
Primary energy save (E_{year})	24 858 534.0		[kWh]
Global Emission saving (EM_{S-i})	3 849.0		[$ton_{CO2\ eq.}$]

Summary of materials employed and main components			
Component			
Bricks	361.4		[ton]
Concrete	2 610.0		[m^3]
Plasterboard	50.0		[ton]
Wood	280.0		[m^3]
Polystyrene	52.2		[ton]
Galvanised steel	33.1		[ton]
Steel	348.8		[ton]
Rockwool	65.0		[ton]
Cast Iron	6.2		[ton]
PVC	1.8		[ton]
Polyethylene	1.2		[ton]
Copper	1.0		[ton]
Polypropylene	0.2		[ton]
Insulation (cellegummi)	201.5		[kg]
Energy saving lamps	77.9		[kW]
Geothermal heat pump	360.0		[kW]
Oil boilers	350.0		[kW]
Aluminium windows	750.0		[m^2]
Wooden windows	398.0		[m^2]

Energy and Environmental Indexes			
Global Energy Requirements (GER)	7 700 417.0		[kWh]
Global Warming Potential (GWP)	1 928.0		[ton $CO_{2\text{-Eq.}}$]
Nutrification Potential (NP)	605.0		[kg PO_4]
Acidification Potential (AP)	6 167.0		[kg SO_2]
Ozone Depletion Potential (ODP)	0.09		[kg CFC_{11}]
Photochemical Ozone Creation Potential (POCP)	807.0		[kg C_2H_4]

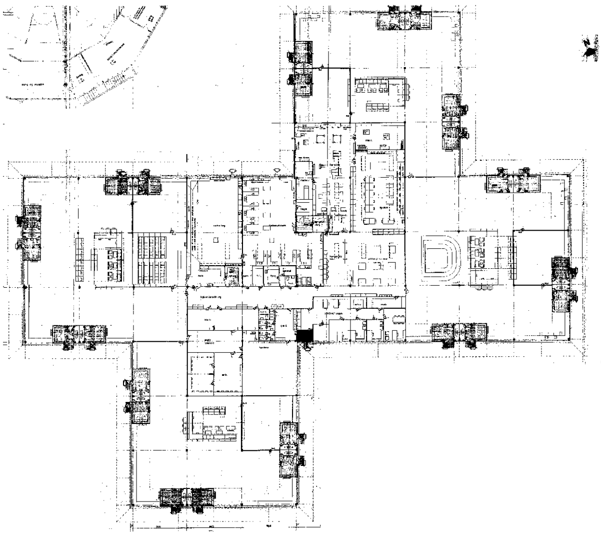
3.5. Construction phase description

3.5.1. Building construction

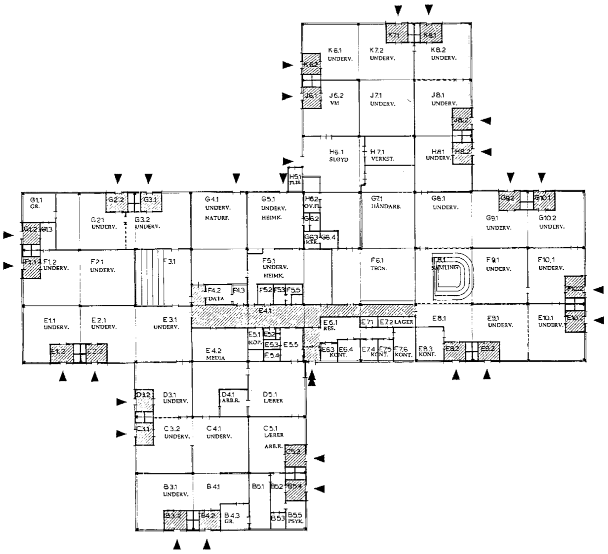
When the planning started, the main objective was to turn the building into a modern local community centre with emphasis on *environment, resources and indoor climate*. The building itself was a challenge with its deep areas with poor daylight condition and the general state of the building envelope.

Originally, the school was built as an “open school” with large teaching areas and few internal walls. There were decentralized entrances to the different base areas. However, over the years new teaching methods and new needs had lead to quite a different floor plan with a number of new walls. This resulted in a labyrinth of a building with many rooms completely

without daylight. It was difficult for students as well as teachers to find the way through the building.
To be able to transform this to a modern school incorporating a local community centre soon proved that all internal walls had to be replaced to allow the flexible solutions such a centre would need.

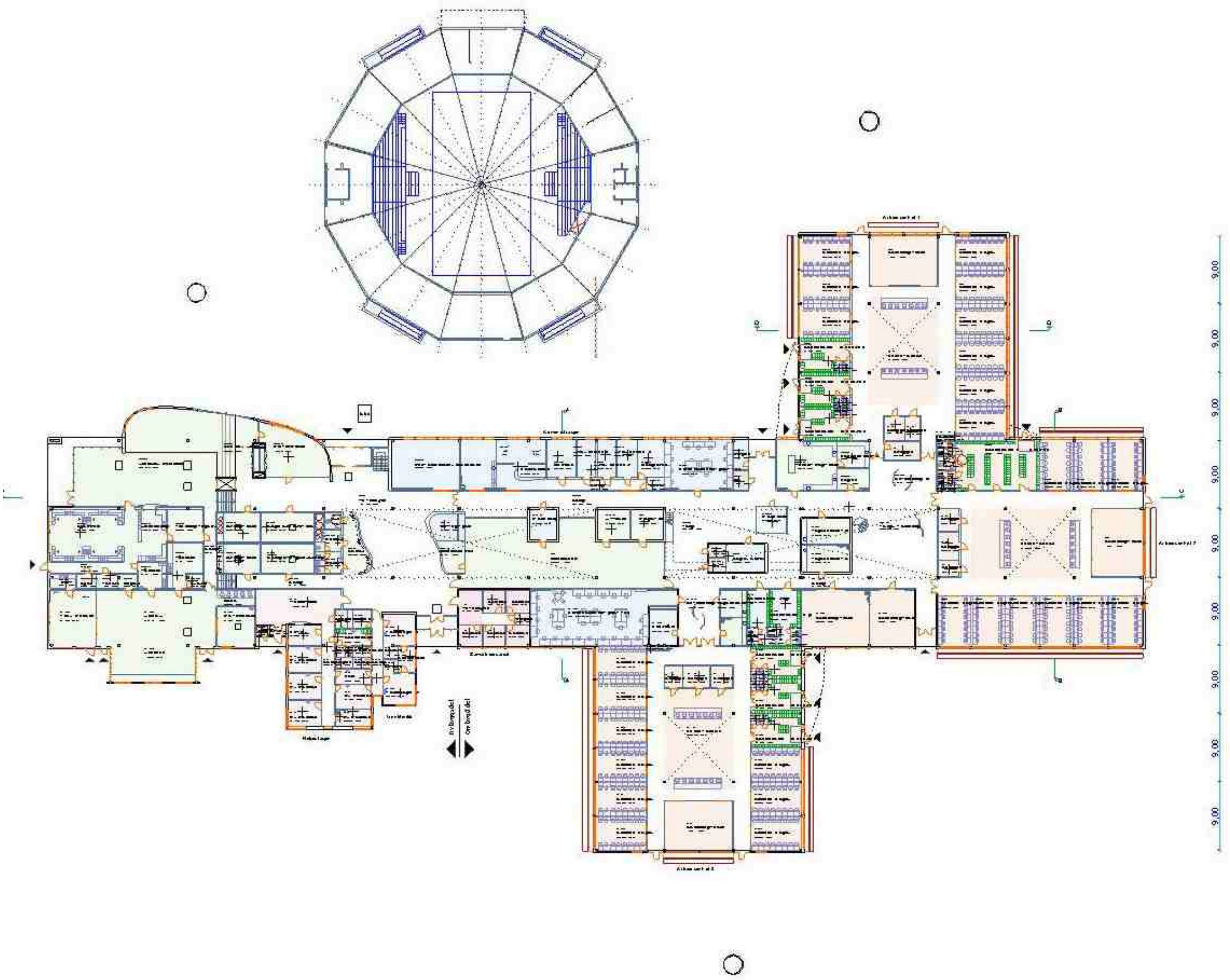


Original plan with decentralized entrances



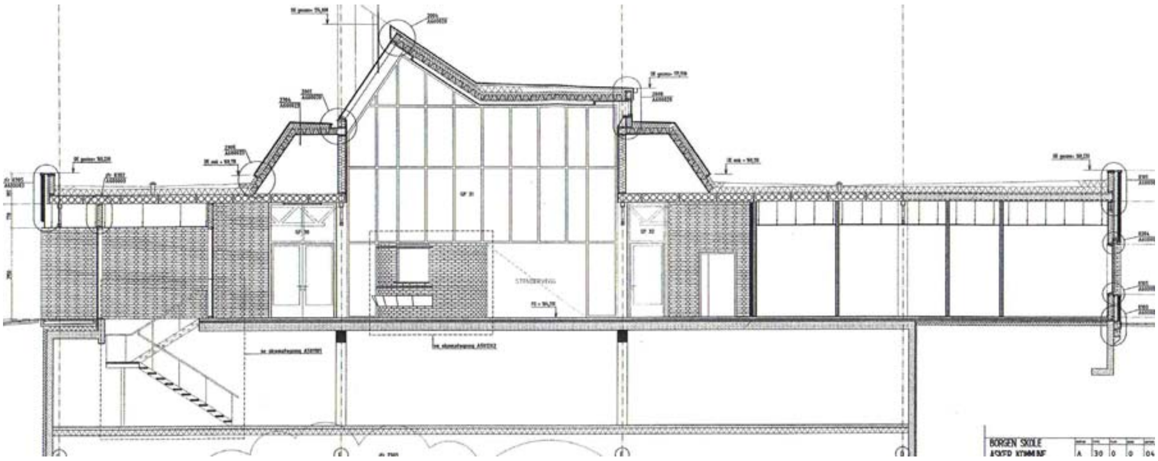
The modified plan before retrofit

The base areas for teaching and learning should allow implementation of new ideas where students have their permanent workspaces in “student’s offices” with room for up to 15 students. Close by there would be rooms for small groups and a large “auditorium” where two “classes” (60 students) could gather for shared studies, performances etc. It soon became evident that the building was not large enough to hold the increased number of students and the new activities. It was therefore necessary to add an extension, where special activities, which should also be accessible to the local community, in the new extension.



The new extended plan

When we started to investigate the problems and possibilities of natural ventilation, active use of daylight and thermal heat, it became evident that we needed to consult specialists. The design group contacted SINTEF research centre in Trondheim to get an evaluation of the concept model. This resulted in an environmental assessment report based on the Norwegian Eco Profile method. The recommendations with respect to natural ventilation, thermal mass, daylight resources, heat pump, space efficiency, artificial light control etc, were then implemented in the project. SINTEF also prepared an energy budget based on recommended constructions and U-values for the building.



Cross section through the main entrance area

Studies were also made for solar PV´s, solar energy collectors and double facades. The conclusion was that no reliable and cost effective system was yet on the market and these solutions were abandoned. On the other hand we came in contact with a group of companies that were working with new concepts for solar collectors and a turnable window that would collect heat from the sun during winter and reflect heat in the summer. This was interesting and we accepted to participate in the project and install prototypes in/on our building and monitor the effects during a test period of one year. The aim is to get necessary feedback to refine the products and prepare them for marketing. The test period was planned to be integrated in the learning process of the school with participation of the students.
Total cost for the SINTEF research and participation in the project amounts to about € 100.000. We believe this was necessary because of the nature and complexity of the project, and it is fair to assume that it reduced design costs for the architect and the consultants, even if it is difficult define the amount.
A complete rehabilitation of the external walls was calculated and turned out to be more expensive than replacing them with completely new walls. We planned to reuse old bricks for internal walls, but in order to do so, they had to be cleaned from old cement and this turned out to more expensive than buying new ones. Instead they were reused as foundations for the outdoor areas.

In order to meet the new requirements for snow loads, roof elements were replaced. Central areas were lifted to allow daylight into the building. Underlying structure was strengthened with steel trusses between the pillars, which had sufficient capacity. Roof insulation was increased to an average thickness of 300 mm, which resulted in a U-value of 0,13 W/m²K.

Walls were rebuilt with 8″ wood framework and brick cladding. Inside was covered with two layers of plasterboards. 200 mm insulation gives a U-value of 0.2 W/m²K, which is within Norwegian requirements. An increase in insulation thickness would be expensive and would yield poor energy benefit.

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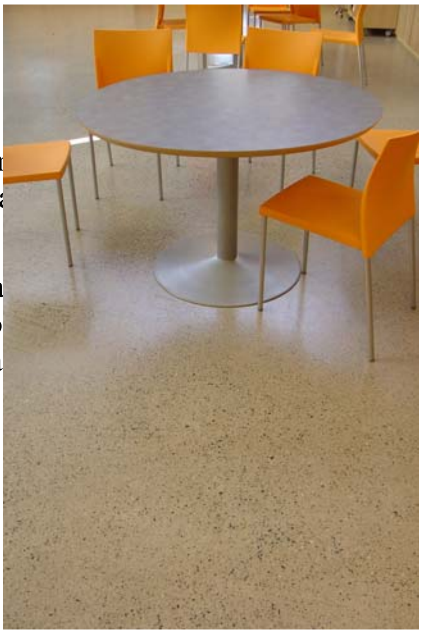


3.5.2. Heating

44 energy wells with an average depth of 150 meters, were drilled into the ground. Heat collectors were installed in the wells and connected to the heat pump with pipelines in the ground. This closed circuit system carries ground heat to the heat pump by means of a water/glycol solution that is circulated by electric pumps. The ground water holds about 6 degrees Celsius, and the heat pump takes out about two degrees that is used to produce hot water. The used heat medium is the pumped back into the wells (collectors) where it is warmed up again by the ground water. The heat pump produces about 2,5 to 3 times more heat than the electric energy used to run the pump, and the small temperature drop of two degrees is sufficient to produce low temperature hot water with a temperature of 45 to 50˚ C. Heat is then distributed in the building by water to radiators under the windows. It is also used to preheat DHW to about 40˚C and the temperature is then lifted to 75˚C by electric heating. During the summer the system can provide cooling by pumping excess heat back into the ground and thus "recharging" the wells.

When using heat pumps, it is mandatory to have a backup system, and two oil burners have been installed. Together they have sufficient capacity to heat the building and supply hot water if the heat pump should fail or during normal maintenance. The heat pump is dimensioned to 60% of total needs. Under normal conditions this is enough and we have so far experienced that the oil burners only kick in a few days during the winter. The energy plant also supplies hot water for heating to the nearby Vardåsen church, which is part of the local community centre, but a not part of the BRITA project. Depending on the interest rate and electric energy prices, payback time was calculated to 10 to 13 years. Since then interest rate has gone down and energy prices up, and payback time is expected to be reduced.

Heat pump

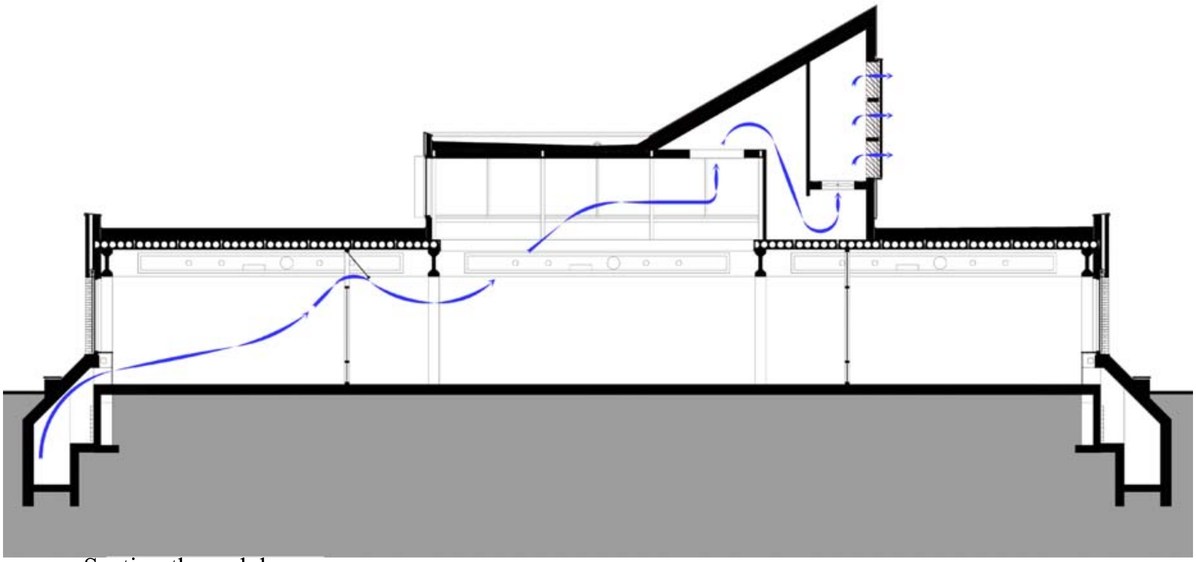
Shunt valves for distribution of heating water

3.5.3. Ventilation

There are three different ventilation systems in the building:

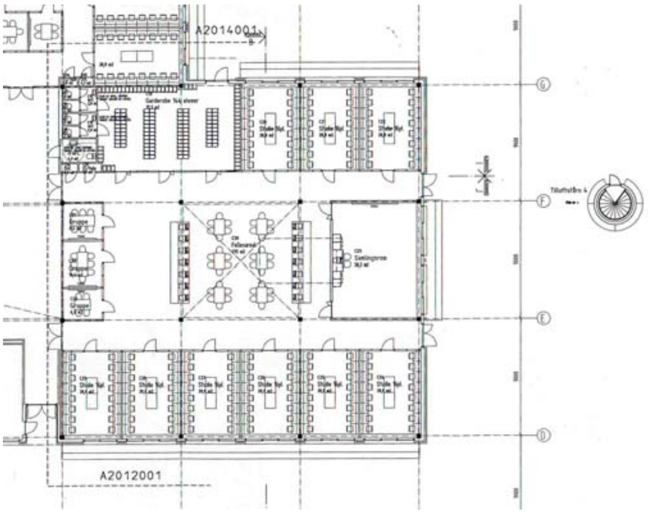
1. Natural hybrid system
2. Natural hybrid system – Swedish model
3. Normal balanced ventilation

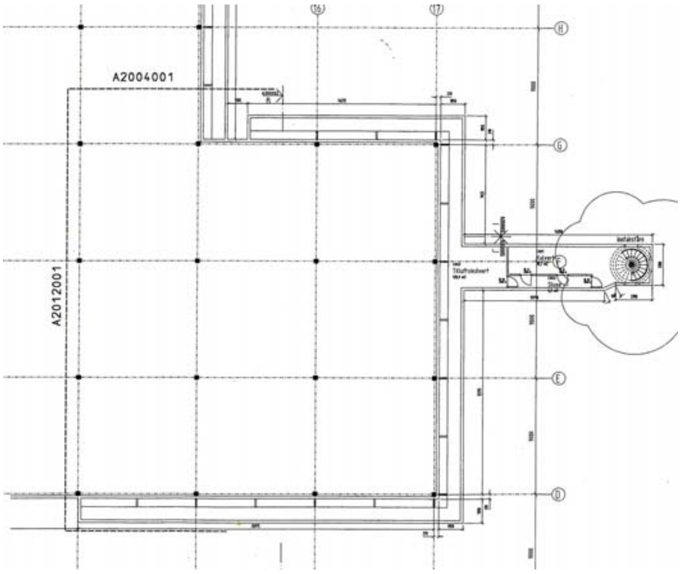
The main ventilation is based on a natural hybrid system, which is designed and built according to the recommendations from SINTEF. Since this was an existing building, air culverts had to be built outside along the foundations. Normally culverts would have been built under the building, but this was not possible in our case. Inlet towers were placed about 14 – 15 meters from the building and the connecting culvert was designed to give room for backup fans, filters and preheating battery. This solution does not give optimal length for the culverts and it was necessary to install fan to ensure air transport during period with low thermal force i.e. during warm periods in the summer.



Section through base area

Culverts serve as filters since low air speed allows particles to settle on the floor. However, because of the reduced length, we had to install additional filters. All culverts have central vacuum cleaning systems to remove sediments from the airflow.





Typical base area with student "offices" Base area culvert system

From the culvert air is let into the room through specially designed grids that allow people to stay very close without feeling a draught. From each room the air is lead to the central area where exhaust towers evacuate the used air. Electrically operated windows in the wall towards the central area regulate airflow through each room. The opening (and the air flow) is regulated by temperature and CO2 sensors in each room and thereby adjusting to the actual need. Exhaust towers are equipped with fans that are activated when natural driving forces are insufficient and heat recovery systems that supply heat to the preheating unit in the culverts.

To benefit from wind forces, a special “wind-turn” system (patented) was developed in close cooperation with the technical university in Trondheim. It ensures that the wind always helps evacuate the air and never build up a pressure that could reduce or stop the natural airflow. A number of movable louvers adjust to the prevailing wind and create suction to the outside through the “wind-turn” element. All exhaust towers on the base areas and the central section is equipped with “wind-turn” elements.

“wind-turn” element without protective cladding

Complete “wind-turn” element

The new section of the building has a Swedish model with culvert under the building. From the culvert air is distributed to the rooms above through double walls of massive brick. Exhaust towers on the roof have electrically operated shutters on both sides that are regulated by temperature and CO_2 sensors, and they automatically open on lee side. The towers have glass roofs, which provide extra daylight to the rooms, but also helps warm up the air and increase air speed. The school kitchen and all wardrobes and toilets have mechanical exhaust systems.

The health centre and administration offices have traditional balanced ventilation systems. The different areas have separate electric meters and heat meters, which makes it possible to monitor the running costs of the different systems. This will be followed up in a case study the next couple of years. It is difficult to estimate potential savings, but the results of the study will clearly show the reduced energy consumption for the building.

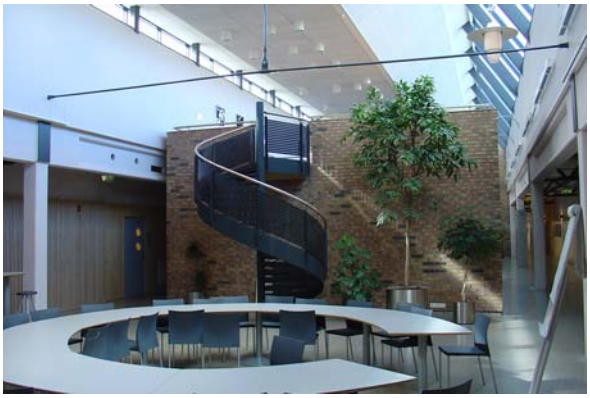
3.5.4. Cooling

The building does not have active cooling. Cooling is very energy consuming and expensive and should not be necessary in a Norwegian climate. The massive construction of the culverts helps to cool the air in the summer and preheat during winter. The temperature is fairly stable at about 6 to 10°C, which is enough to cool summer air to a comfortable level. In very hot periods it necessary to run the ventilation during the night to cool the building elements, which to a great extent consist of heavy materials with good thermal capacity. This in turn helps keep the temperature during the day.

3.5.5. Lighting systems

Active use of daylight reduces electric power consumption used for lighting. The large skylight

facing north at an angle does not let direct sunlight and heat into the building, but greatly increases the level of daylight in the central area. The narrow window facing the south also contributes without letting in much heat. To optimise the effect of daylight, all artificial lights are adjustable and regulated by light sensors. In addition, light is also regulated by motion sensors that will turn the light on when someone enters the room, if conditions require so. When a room is left empty, the light will automatically be turned off after a preset time elapse. The IR-sensors also serve as detectors for the burglar alarm.

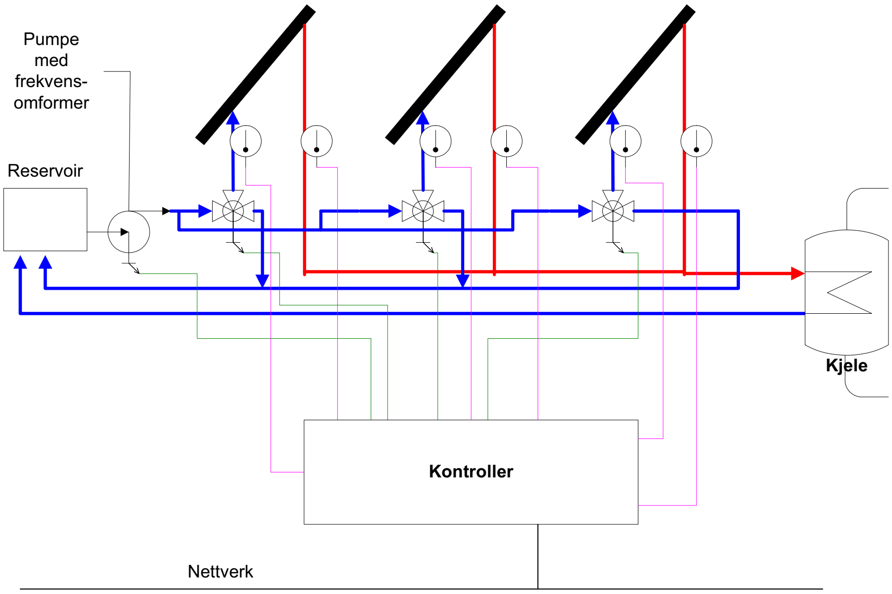


Studies have shown that daylight is good for the human health and should be used more actively than the case is today for many buildings. In addition to reducing costs for electric lighting, it makes buildings more agreeable places to be. The high ceiling in the central areas give a feeling of openness that contributes to the good air quality and the well being of the people working in the building.

3.5.6. Solar thermal collectors

Planning and design of the solar collector has been delayed several times. SINTEF in Trondheim has been involved in simulation studies of potential energy gain under different solar conditions and different locations. Naturally, the results improve as one moves south, but the low sun in the winter gives good results for vertical collectors. The study indicates that collectors should have mountings that allow seasonal adjustments. SINTEF has also made studies of surface temperatures for solar collectors. Preliminary results indicate temperatures from approximately 22 to 43°C for the southern Norway region. “Our” collector with highly efficient glass and liquid heat media has not been tested and the project group expects to obtain higher temperatures. At any rate, for production of domestic hot water it will probably be necessary to connect a heat pump to raise the temperature to a level where problems with legionella is avoided. This may not be a problem with closed circuits for heating only.

Concept for solar collector system



Design has been completed and a prototype was made in the fall of 2007. It was sent to one of the participating companies for technical tests. There have been problems with leaks around the water pipes connecting the collector to the circulation pump unit.
However, the many delays meant that the solar collector was not ready for installation at Borgen by the time the Brita project was terminated. The school has announced that it is willing to take part in a test program at Bergen, provided that the participating companies cover all costs.

3.5.7. ACC windows

The developer of the ACC window has encountered similar problems. Preliminary design for window frames and sashes have been completed and a prototype for the special hinges has been produced. But, the production of test units is far behind schedule and the windows will not be installed at Bergen for testing as planned.

3.5.8. BEMS

The advanced BEMS installed at Borgen ensures optimal performance of the technical installations. Temperature, CO2 and air- and water flow are monitored continuously. Set values can be adjusted individually for different rooms. Critical alarms are sent to building managers by SMS and they can monitor and adjust settings through a closed network from a centrally located operation room.

Total energy consumption, electric and oil, is also monitored continuously along with water consumption and the outdoor temperature. This way we have full control over the buildings energy situation at any time.

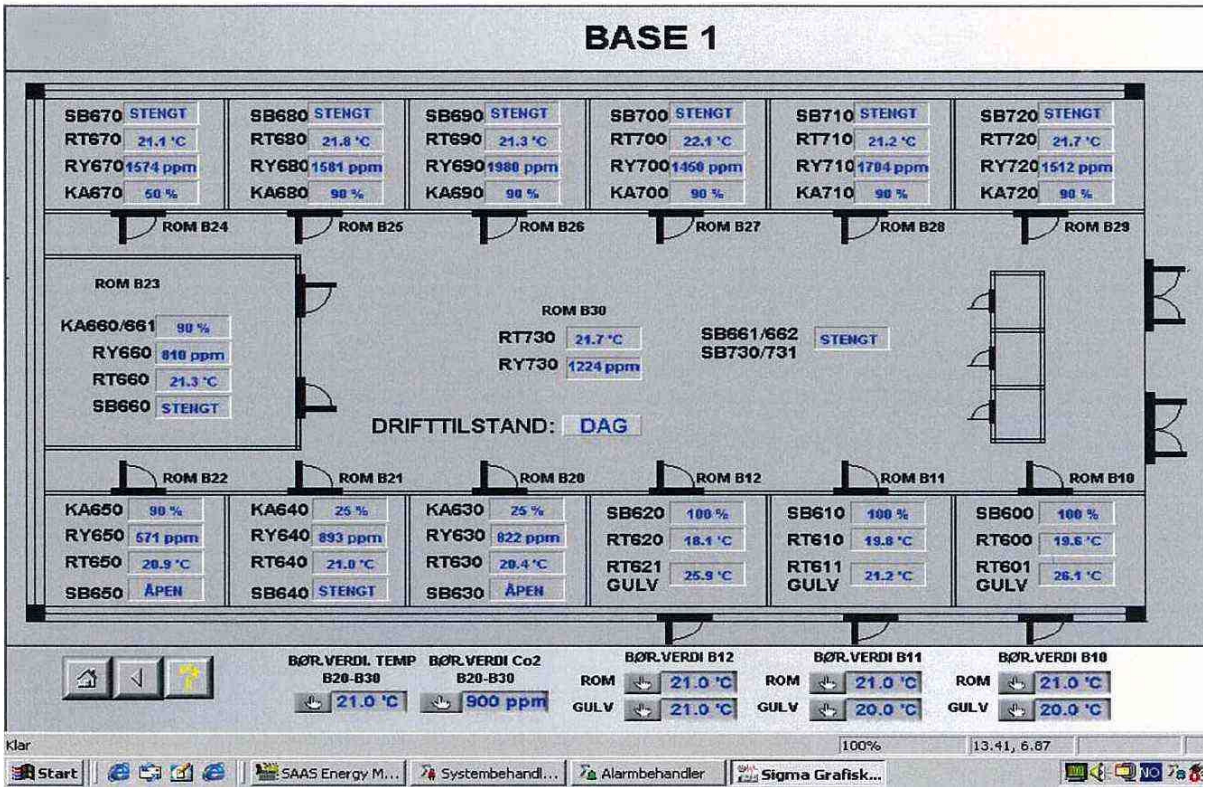
3.6. Monitoring

3.6.1. Monitoring plan

At Borgen we do not have a special monitoring plan, since all technical installations and energy consumption is monitored continuously and followed up by our building manager. The aim is to refine operations and reduce energy consumption to a minimum while maintaining a good indoor climate.

The following parameters are measured:

- Energy and Water Consumption
  - Temperature drop
  - Flows
  - Oil
  - Electricity
  - Water



BASE 1

SB670 STENGT
RT670 21.1 °C
RY670 1574 ppm
KA670 50 %

SB680 STENGT
RT680 21.8 °C
RY680 1581 ppm
KA680 90 %

SB690 STENGT
RT690 21.3 °C
RY690 1980 ppm
KA690 90 %

SB700 STENGT
RT700 22.1 °C
RY700 1450 ppm
KA700 90 %

SB710 STENGT
RT710 21.2 °C
RY710 1704 ppm
KA710 90 %

SB720 STENGT
RT720 21.7 °C
RY720 1512 ppm
KA720 90 %

ROM B23
KA660/661 90 %
RY660 810 ppm
RT660 21.3 °C
SB660 STENGT

ROM B30
RT730 21.7 °C
RY730 1224 ppm

SB661/662
SB730/731 STENGT

DRIFTTILSTAND: DAG

KA650 90 %
RY650 571 ppm
RT650 20.9 °C
SB650 ÅPEN

KA640 25 %
RY640 893 ppm
RT640 21.0 °C
SB640 STENGT

KA630 25 %
RY630 822 ppm
RT630 20.4 °C
SB630 ÅPEN

SB620 100 %
RT620 18.1 °C
RT621 GULV 25.9 °C

SB610 100 %
RT610 19.8 °C
RT611 GULV 21.2 °C

SB600 100 %
RT600 19.6 °C
RT601 GULV 26.1 °C

BØR.VERDI. TEMP B20-B30 21.0 °C
BØR.VERDI Co2 B20-B30 900 ppm

BØR.VERDI B12 ROM 21.0 °C GULV 21.0 °C
BØR.VERDI B11 ROM 21.0 °C GULV 20.0 °C
BØR.VERDI B10 ROM 21.0 °C GULV 20.0 °C

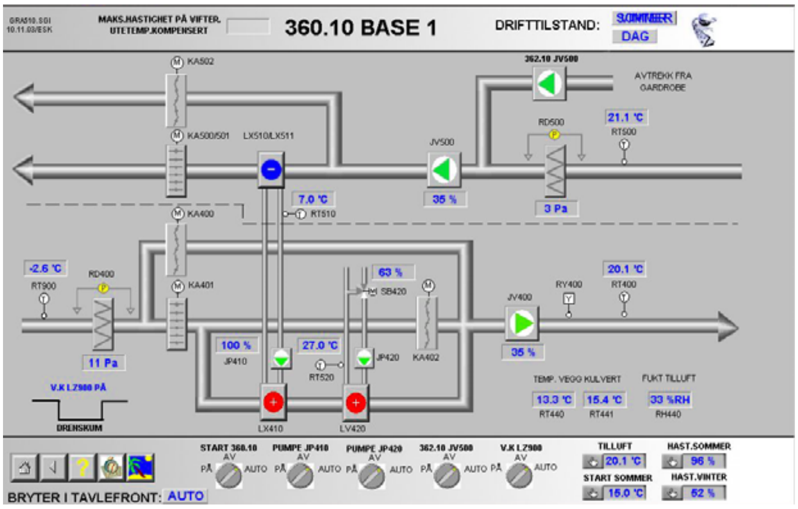
Klar 100% 13.41, 6.87

Screen dump from BEMS monitor

- ○ Local Weather

A weather station is installed on the building and measures:

  - Temperature
  - Windspeed
  - Wind direction
- ○ Thermal Comfort
  - Air temperature
  - Air velocity
- ○ Indoor Air Quality
  - CO_2



360.10 BASE 1

DRIFTTILSTAND: SOMMER DAG

MAKS.HASTIGHET PÅ VIFTER. UTETEMP.KOMPENSERT

BRYTER I TAVLEFRONT: AUTO

TILLUFT 20.1 °C
START SOMMER 15.0 °C
HAST.SOMMER 96 %
HAST.VINTER 52 %

Ventilation system base 1

3.7. Data analysis

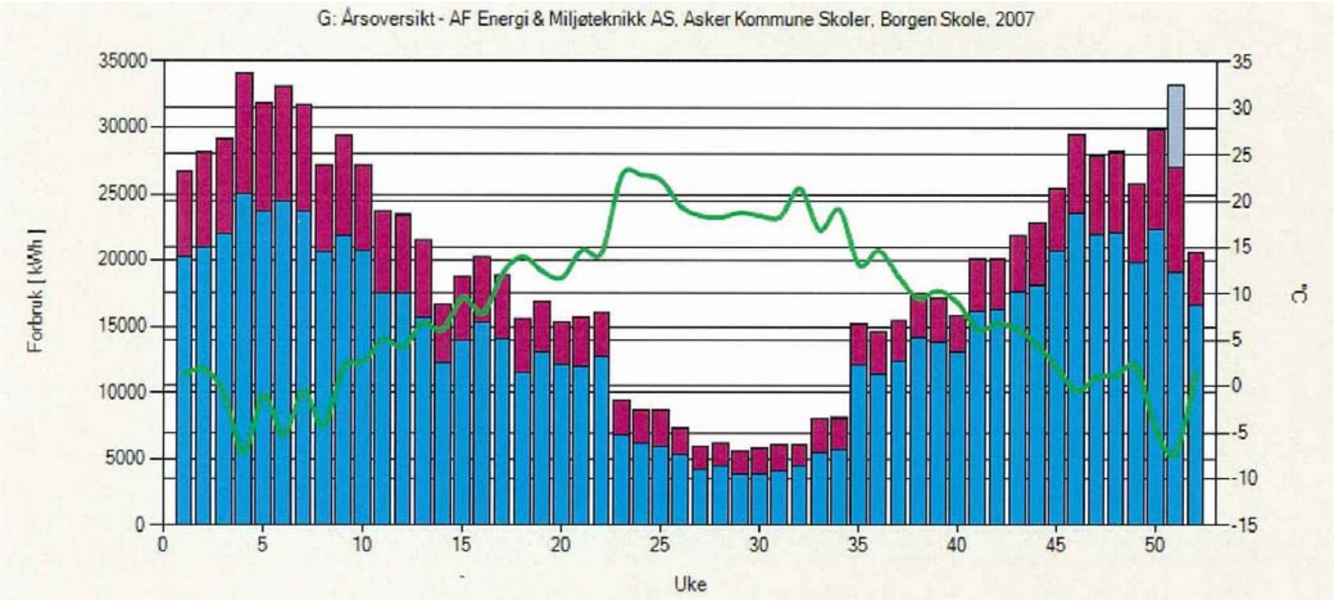
3.7.1. Local Weather

Consumption of oil and electric power is monitored every hour of every day along with the outside temperature. This way we have a complete record of energy consumption and the temperature through the year. The municipality of Asker has engaged AF Miljøteknikk, an independent firm that specializes in energy and environment improvements, to help save energy and improve environment in our existing building stock. AF Miljøsteknikk has helped us calculate the degree days correction on basis of meteorological statistics for Asker.

3.7.2. Energy consumption

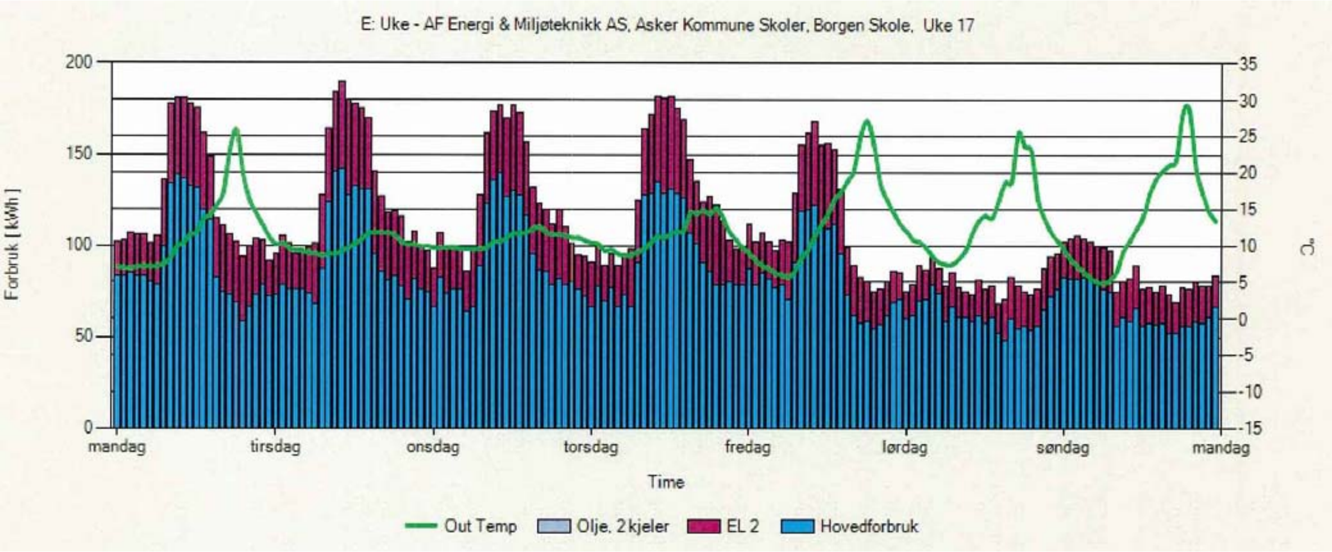
2.3.7.1. Energy Demand: Electricity and oil (measured total energy consumption 2007)

	[kWh/m^{2}a]	Total annual (kWh)
Electricity		1.001.826
Oil		6.174
Total consumption		1.008.000
Delivered to the church		-116.500
Total consumption Borgen	**98,5**	**891.500**
Degree days correction		+31.203
Corrected total energy consumption	**102**	**922.703**



Total energy consumption and mean outdoor temperature 2007

Blue: Electric power for heating and ventilation
Red: Lighting and appliances
Grey: Oil
Green: Mean outdoor temperature



Consumption during week 17, 2007

2.3.7.2. Water consumption

		Total for the whole building
Water	0,12 m^3/m^2a	1.050 m^3/a

3.7.3. Thermal comfort

3.3.7.1. Calculated on the basis of measured data

The BEMS system monitors temperature in all rooms in the base areas on an hourly basis. The results show that temperature is very close to the set value of 21° C during school hours. This is also in accordance with the two user comfort studies conducted.

3.3.7.2. Reported on basis of users satisfaction enquiry

The first user satisfaction study was conducted among the students in the three base areas. During the 2-week enquiry period, the airflow was regulated differently in the three bases to study the effect on the students' perception of air quality and temperature. One base was regulated by temperature alone; another by CO2 values and the third by a combination of temperature and CO2 (which represented no change to normal regulation). The study showed surprisingly small differences in temperatures, but the conclusion was that temperature is very important for the perception of indoor climate quality. If the temperature was low, students tended to define air quality as poor even if CO2 values were far below the set value of 1000 ppm. On the other hand, if the temperature was between 21 and 22° C they defined the air quality as very good even if CO2 values were as high as 1500 ppm.

3.7.4. Overall User Satisfaction (gender specific surveys on indoor environment conditions)

The second comfort study was conducted among the teachers and was more comprehensive than the first one. Over all the majority of the teachers was quite satisfied with the indoor climate and did not want any changes. There were other issues they were dissatisfied with, but they were more related to teaching facilities and teachers workspace.

3.8. Summary

3.8.1. Overall energy and water consumption

	Before retrofit	After Retrofit Foreseen	Saved foreseen	After Retrofit Measured	Saved measured
Primary Energy [kWh/m^2 a]	280	111	169	102	178
Water [m^3/m^2 a]	na	na	na	0,12	

3.8.2. Overall Economic evaluation

Total extra costs (Foreseen) [EUR]	Total extra costs (Observed) [EUR]	Saving (Foreseen) [EUR/a]	Saving (Observed) [EUR/a]	Payback foreseen	Payback observed
889.000	**1.015.000**	**100.893**	**106.266**	**8,8**	**9,6**

Energy costs used for calculation (2008):

Oil	0,10 €/kWh
Electric	0,10 €/kWh

3.9. Lessons learned

- Energy consumption is lower than our expectations. This is the result of an effective heat pump combined with good insulation and windows. The active use of daylight and automatic regulation of electric lights also contribute to the low energy consumption. The same is the case for the natural hybrid ventilation that reduces power for ventilation fans drastically.
- BEMS system has helped us optimize operation of technical installations and put focus on energy consumption.
- Problems with sound carried from one room to another through ventilation culverts. Measures had to be taken to minimize the problem. There have also been complaints from neighbours because of noise spread through exhaust towers on the roof. This is particularly the case from the music rooms.
- Building underground culverts along existing constructions is difficult, time consuming and expensive. Natural ventilation with underground culverts is probably most suitable in new buildings, where they can be incorporated in the basement/foundations. For retrofit, other solutions should be considered, for instance fresh air inlet through double facades or through special convectors under the windows.
- Moisture from rain and snow enters the system from the inlet towers and caused the lower part of the wall enclosing the filter unit to become moist. Design should therefore focus on preventing water from entering ventilation culverts.
- IR sensors for light regulation combined with burglar alarm has caused problems because the early morning sun hits the sensor and triggers the alarm. Sensors had to be moved to a corner and directed inwards.
- The sophisticated BEMS system requires skilled operators and a long testing and adjustment period.
- Technical personnel should be educated during the building period to get acquainted with the technical installations before the building is opened.

Before

After

4. Hol Church, Hagafoss

Author: Sivilarkitekt Harald N. Røstvik AS

4.1. General data

4.1.1. General information

Year of construction:	1924
Year of renovation (start):	2006-2007
Number of storey:	1

Heated volume	Approx. 6000 m^3
Cubic contents, volume	Approx. 6150 m^3
Gross area	600 m^2
Living area	
Floor area (heated space)	550 m^2 (net)
Window/glass areas	5 %

4.1.2. Site

The church is located in a mountain valley in the centre of Norway's Southern part, located by the railway line half way between Oslo and Bergen and only minutes form the popular winter ski resort Geilo. 60 degrees North, 8 degrees East.

4.1.3. Building type

Church.

4.2. Before retrofit

4.2.1. Building construction

The church is a timber construction with steep roof indicating elements from the stave-church era.
The walls sit on a stone foundation raised only slightly from the ground. It's extremely high interior of 20 metres equals the height of eight standard dwelling storeys, which is an energy challenge in itself since hot air rises and stays under the ceiling rather than close to people's feet. The challenge of comfort is hence a crucial element of this project.

The un-insulated timber floor was not covering a full-scale cellar, only a crawl space with varying height up to one meter. The timber roof construction and walls were also un-insulated. Windows and doors were not closing properly, had no gaskets and were letting extremely cold draughts into the building. This both brought the energy need up and also caused considerable comfort problems; no matter how much energy was used it still felt cold as the outdoor temperature fell down to minus 20-30 degrees C.

No drawings of the church have been made available to the project team. All studies, measurements and planning drawings have had to be done on site and with the antiquarian authorities sitting in Oslo, 300 kilometres away and with low travelling budgets, communication has been a challenge.

4.2.2. Existing heating, ventilation, cooling, lighting systems

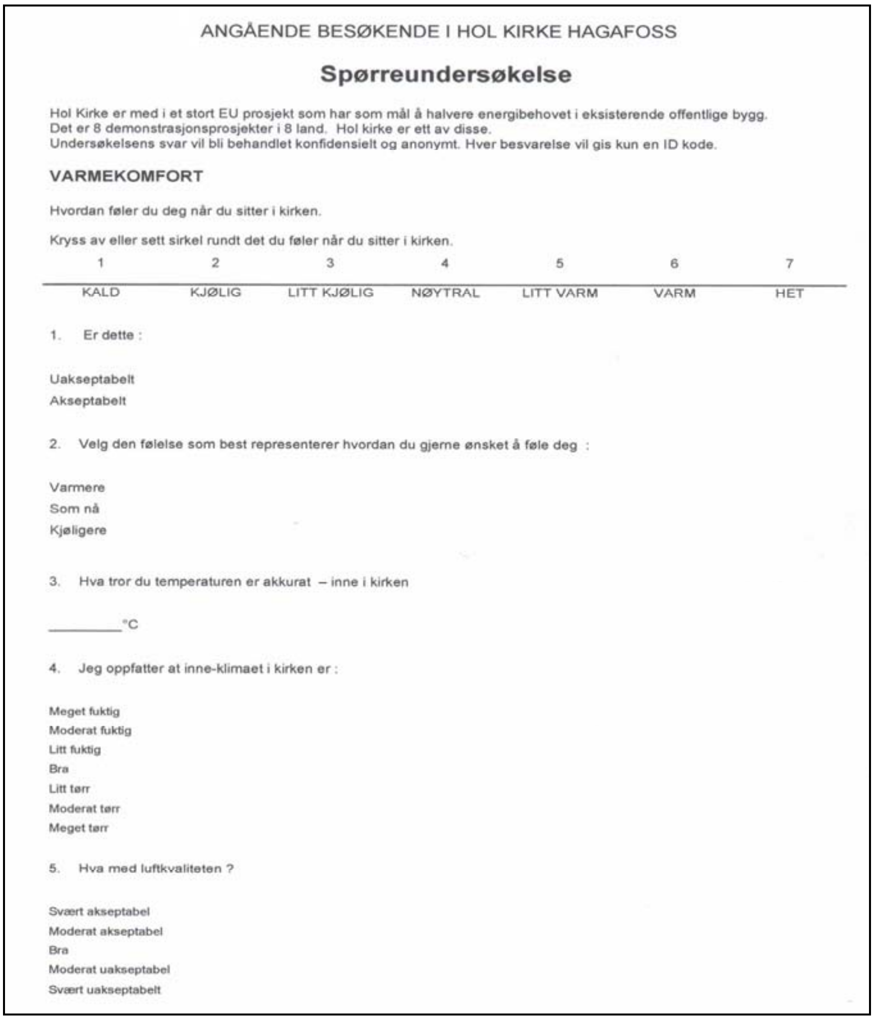
The existing heating system is typical of Norway.
Due to the huge hydropower production, electric resistance heating is common. The system has a total capacity of 70 kW and heaters are positioned under the benches. Due to the draughts, the comfort level has not been reached during cold spells in spite of going full capacity for days in advance to heat the church for typical activities like approximately 21 services a year, 15 funerals, 5 wedding and 10 choir and other cultural events. The solar radiation normally gained passively through windows does not help either, since the church has only very small windows. Heating the church from cold to warm hence takes up to three days during winter.

4.2.3. Energy use

	Measured year (2002)	Total for the whole building
Space heating	220 kWh/m^2 a	122 100 kWh/a
Electricity for lights etc	37 kWh/m^{2}a	20 535 kWh/a

4.2.4. User satisfaction before retrofit

Complaints on cold indoor climate and cold draughts were numerous and one of the reasons for initiating retrofitting of the church. The complaints were consistent, growing in numbers and verbal. No need for detailed data collection on this issue was hence necessary. Below is the two page form in Norwegian that was handed out to the church-goers prior to retrofit.



ANGÅENDE BESØKENDE I HOL KIRKE HAGAFOSS

Spørreundersøkelse

Hol Kirke er med i et stort EU prosjekt som har som mål å halvere energibehovet i eksisterende offentlige bygg.
Det er 8 demonstrasjonsprosjekter i 8 land. Hol kirke er ett av disse.
Undersøkelsens svar vil bli behandlet konfidensielt og anonymt. Hver besvarelse vil gis kun en ID kode.

VARMEKOMFORT

Hvordan føler du deg når du sitter i kirken.

Kryss av eller sett sirkel rundt det du føler når du sitter i kirken.

1	2	3	4	5	6	7
KALD	KJØLIG	LITT KJØLIG	NØYTRAL	LITT VARM	VARM	HET

1. Er dette :

Uakseptabelt
Akseptabelt

2. Velg den følelse som best representerer hvordan du gjerne ønsket å føle deg :

Varmere
Som nå
Kjøligere

3. Hva tror du temperaturen er akkurat – inne i kirken

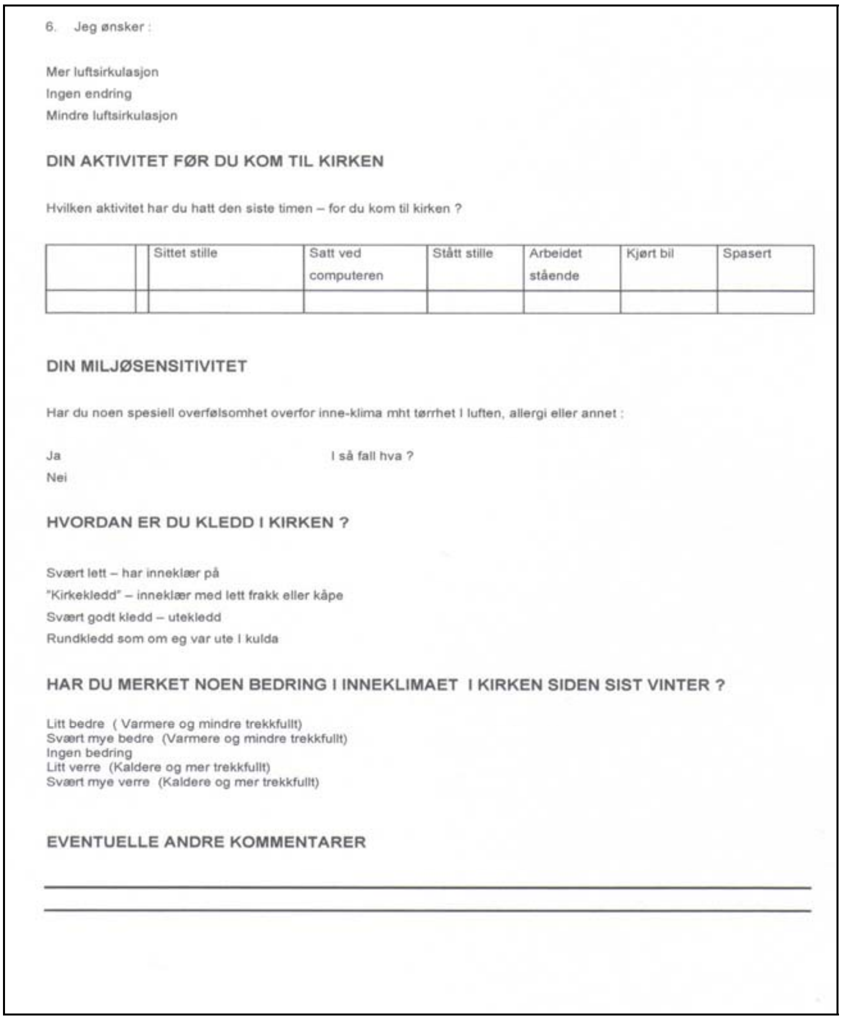
_________°C

4. Jeg oppfatter at inne-klimaet i kirken er :

Meget fuktig
Moderat fuktig
Litt fuktig
Bra
Litt tørr
Moderat tørr
Meget tørr

5. Hva med luftkvaliteten ?

Svært akseptabel
Moderat akseptabel
Bra
Moderat uakseptabel
Svært uakseptabelt



6. Jeg ønsker :

Mer luftsirkulasjon
Ingen endring
Mindre luftsirkulasjon

DIN AKTIVITET FØR DU KOM TIL KIRKEN

Hvilken aktivitet har du hatt den siste timen – for du kom til kirken ?

		Sittet stille	Satt ved computeren	Stått stille	Arbeidet stående	Kjørt bil	Spasert

DIN MILJØSENSITIVITET

Har du noen spesiell overfølsomhet overfor inne-klima mht tørrhet I luften, allergi eller annet :

Ja I så fall hva ?
Nei

HVORDAN ER DU KLEDD I KIRKEN ?

Svært lett – har inneklær på
"Kirkekledd" – inneklær med lett frakk eller kåpe
Svært godt kledd – utekledd
Rundkledd som om eg var ute I kulda

HAR DU MERKET NOEN BEDRING I INNEKLIMAET I KIRKEN SIDEN SIST VINTER ?

Litt bedre (Varmere og mindre trekkfullt)
Svært mye bedre (Varmere og mindre trekkfullt)
Ingen bedring
Litt verre (Kaldere og mer trekkfullt)
Svært mye verre (Kaldere og mer trekkfullt)

EVENTUELLE ANDRE KOMMENTARER

4.2.5. Building construction

	Pre retrofit U-value [w/m^2]	Post retrofit Uvalue [w/m^2]
Walls Timber (Not changed – no retrofit)		
Roof (162 m2 loft – horizontal)	0,80	0,11
Windows Double (Not changed –no retrofit)		
Floors (372 m2 ground floor)	0,80	0,19

4.2.6. Heating

The solutions sought can be split into three main categories :

- Insulation reducing heat loss through the envelope, coupled with improved gaskets to avoid drafts from windows and doors. This has proved to be a considerable comfort level raise without it necessarily having a huge impact on energy need, since the system before the retrofit was going full speed and still not managing to raise the comfort level to an acceptable level.
- A vertical two metres high, 75 cm diameter round air canon of 4.200 m3/hour (drawing only 160 W) "shoots" unheated air upwards to replace the heated air under the ceiling. This process is normally started an hour before the service and it moves the warm air under the ceiling down to where people are seated. It has proven to be an efficient comfort measure that improves the feeling of comfort.

- In this region of Norway, when it is cold, it is normally sunny and not windy. There is also a lot of white reflective snow in this region. An air based solar thermal system is selected.

Air ”canon”.

One meter high crawlspace.

Double windows with gaskets.

4.2.7. Ventilation

There was no ventilation system in the church prior to refurbishment, nor after. The huge volume per person ensures acceptable air quality during service.

4.2.8. Cooling

No need for cooling before or after due to solid timber construction and relatively small window area. Overheating is no problem.

4.2.9. Lighting systems

Relatively efficient fluorescent bulbs installed before retrofit. Routines are improved now to reduce operational hours.

4.2.10. Control strategy

Since the church has a very simple energy system, a complicated Building Energy Management System (BEMS) has not been designed and installed to control the heating systems.

Instead, a close dialogue with the caretaker has been initiated and valuable exchange of information, through discussion and analysis has been started to initiate measures, check routines and improve routines while continuously supporting the caretaker. This has been the philosophy of this project.

To ensure optimum control of the building and thus save energy, a continuous process of dialogue between the planners and the caretaker has proved fruitful. This also has resulted in a considerable awareness building that in itself seems to have shown results in terms of lower energy bills.

Due to the huge distances in the area, between the caretaker’s home and the church, an automated “Ring the church warm” system has being installed. Formerly the caretaker had to physically travel by his car 25 km each way to turn the heat on high, days before a major church activity. If this happened during a time when he was planning to be elsewhere, he might have to turn on the heat a day or two earlier than normally necessary to meet his other commitments. By installing the new “Ring the church warm” system, he does not have to travel to switch heaters on. This saves a great number of “heating the church full speed unnecessary days” and a great number of driven car-kilometres amounting to 51 trips to the church and 51 back home to switch on in advance of events.

The energy savings of reducing the number of driven kilometres by 51trips x 25km x 2 = 2550 km, means annual petrol energy saving of approximately 255 litres and CO2 emissions of half a ton (500 kilos) every year. As he is normally present during events in the church he normally switches off after the event so there is no extra travel involved then.

4.2.11. Predicted energy savings

Energy saving measures, heating, cooling, ventilation	[kWh/m^{2}a]	Total [kWh/a]
Improved insulation	48	27 115
Solar thermal	15	8 000
Total heating energy savings	63	35 115

Energy saving measures, electricity	[kWh/m^{2}a]	Total [kWh/a]
Efficient lighting	5	2 700
Solar PV	5	2 700
Total heating energy savings	10	5 400

4.2.12. Predicted costs and payback

Energy saving measure/investment	Area [m²]	Total costs [EUR]	Saving [EUR/a]	Pay-back periods [a]
Insulation of facades		50 200	4 000	12
Solar heating system		35 500	1 200	28
Solar PV		43 000	450	90
Efficient lighting		8 000	450	17
Total		**136 700**	**6 100**	**22**

Energy costs used for the payback calculation (2004):
Thermal : 1,20 NOK/kWh = 0,15 Euro
Electric: 1,20 NOK/kWh = 0,15 Euro
In Norway electricity is produced from local hydropower and is used even for heating of this type of building through resistance heaters. The price of thermal energy is hence set at the same level as electric.

4.3. Life Cycle Assessment

4.3.1. Brief Description of the retrofit action

The retrofit was done on an ancient timber church. The actions included the removal of rotted timber and installation of rockwool insulation, the introduction of a solar thermal system to reduce electric power use for heating, a PV system to run fans for warm air transport, and installation of energy efficient light bulbs

Primary energy saving and emissions			
Primary energy save (E_{year})	2 603 877.0		[kWh]
Global Emission saving (EM_{S-i})	499.5		[ton$_{CO2\ eq.}$]

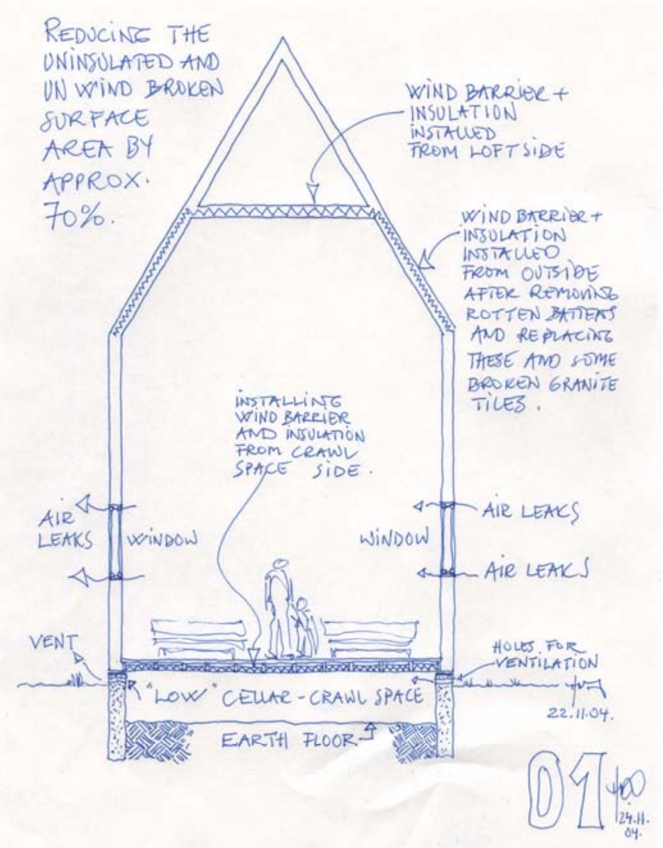
Summary of materials employed and main components			
Component			
Rockwool	5.7		[ton]
Concrete	0.25		[m^3]
Steel	93.5		[kg]
Rubber	12.5		[kg]
Polystyrene	12.0		[kg]
E-saving lamps (power)	0.275		[kW]
PV plant	35.0		[W]

Energy and Environmental Indexes			
Global Energy Requirements (GER)	44 898.0		[kWh]
Global Warming Potential (GWP)	9.7		[ton $CO_{2\text{-Eq.}}$]
Nutrification Potential (NP)	7.0		[kg PO_4]
Acidification Potential (AP)	56.0		[kg SO_2]
Ozone Depletion Potential (ODP)	0.001		[kg CFC_{11}]
Photochemical Ozone Creation Potential (POCP)	5.6		[kg C_2H_4]

Synthesis Indexes			
Energy Payback Time ($E_{\text{-PT}}$)	0.51		[year]
Emission Payback Time ($EM_{\text{-PT}}$)	0.65		[year]
Energy Return Ratio (E_R)	58.0		

4.4. Construction phase description

A very slow process due to the resistance form the antiquarian authorities, but all works were finally approved and carried out successfully.


REDUCING THE UNINSULATED AND UN WIND BROKEN SURFACE AREA BY APPROX. 70%.
WIND BARRIER + INSULATION INSTALLED FROM LOFT SIDE
WIND BARRIER + INSULATION INSTALLED FROM OUTSIDE AFTER REMOVING ROTTEN BATTENS AND REPLACING THESE AND SOME BROKEN GRANITE TILES.
INSTALLING WIND BARRIER AND INSULATION FROM CRAWL SPACE SIDE.
AIR LEAKS
WINDOW
WINDOW
AIR LEAKS
AIR LEAKS
VENT
HOLES FOR VENTILATION
"LOW" CELLAR - CRAWL SPACE
EARTH FLOOR
22.11.04.
01
1/100
24.11.04.

The solar system in place.

The Hol Church project has uncovered the huge challenges facing a considerable part of the protected buildings in Europe. These buildings are crucial as regards reducing energy need in

the building stock, since they will be with us for decades and centuries. If we do not reduce the energy need in existing buildings, the overall energy need in European buildings cannot be reduced.
To achieve energy need reductions in existing buildings antiquarian authorities' restrictions have to be relaxed and innovative methods to both introduce energy efficiency measures and apply renewables without coming into unacceptable conflict with the rich architectural heritage such buildings represents, have to be addressed.
The Hol Church project shows that steadfastness and endurance coupled with innovation can lead to success.
The challenge in this project was to show how energy efficient solutions could be applied, in spite of it being a listed building under the protective wings of the antiquarian authorities, which in principle allowed no change at all to the structure.

"*If we are going to secure the future of coming generations, we must protect the environment. The church has a responsibility in this context and we will support work to stop negative environmental trends.*
We will show examples and shout, "it works".
We will support all good forces and help provide politicians with courage to initiate necessary measures".

Bishop of Tunsberg Laila Riksaasen Dahl in her New Year speech 2006

4.4.1. Building construction

After having received refusal from the Antiquarian Authorities (AA) for insulation works, appeals have led to compromises. The floor was insulated from below through the crawl space, which indeed was a difficult job. The details for the chosen insulation method, was worked out with the AA to avoid dampness leading to rotting of the construction.
The motion of the same refusal/acceptance procedures were carried out as regards the flat part of the roof.

The church argued that the existing ceiling that had very dry sawdust covering the ceiling was a fire risk.
The AA finally accepted that argument.

The ceiling was insulated from above. This was also an extremely complicated work task, as bringing in materials could damage the church interior.

As the picture shows, materials were instead crane-lifted into the building and through a window at a high position.
The windows consist of two layers of glass with a 70 mm gap.
The windows and doors were adjusted to close properly.
They were equipped with rubber gaskets.

4.4.2. Solar Thermal

An air based solar thermal system at a distance from the building has been developed. Since the AA has to approve everything within a radius of 65 metres of the church, this instalment has been rejected and also was rejected through the appeal round. However, since the Bishop can overrule the AA by refusing to accept their advice, the last resort was to appeal to the Bishop. This worked and the Bishop cut through and overruled the AA. The compromise that she has proposed and which has been accepted means reducing the height of the solar thermal system to six metres, which also reduces the area and to increase the distance from the church to the absorber.

The vertical system is connected to the church through an earth-sheltered insulated duct bringing heated air to the church and sucking air from the church in a similar duct returning to the solar absorber. The air is moved through the solar absorber and from the absorber to the church by two small fans connected to a solar PV system that starts, stops and regulates air speed depending on how bright the sunshine is. It is in other words an autonomous and self-regulating system.

4.4.3. Solar PV

A double function scaled-down solar PV system is installed to run the fan that moves solar heated air from the solar thermal absorber into the church space to provide space heating. It is automatically switching the solar thermal flow on and off depending on the solar radiation, which is beautifully coordinated with the available energy or lack of so in the solar thermal system. No complicated controls were hence needed.

A minor solar PV system was originally planned. However, the experience of the restrictions from the AA have led to a rethink of this type of solution, for the several reasons :

- The contribution per m2 is small compared to solar thermal, which delivers 3-4 times more energy per m2 absorber at a lower cost.
- The cost of PV is high which leads to a high payback time (90 years).
- A double function sought, whereby the solar PV is linked to an energy supply system (solar thermal).

4.5. Monitoring

4.5.1. Monitoring plan

- Monitoring of total energy use started 1 May 2007.
  Monitoring of bought energy (electric hydropower).
- Month by month monitoring through meter reading with digital photo
  as documentation every first day of month.

• Results:	May 2007	5.920 kWh/month
	June	2.440
	July	1.560
	August	1.840
	September	3.160
	October	7.000
	November	5.280
	December	18.720
	January 2008	8.000
	February	8.650
	March	10.280
	April	4.710

SUM **78.040** kWh/year (141 kWh/m2/year)

• Comparison pre-BRITA (benchmark): Energy need per year :
142.635 kWh/year (257 kWh/m2/year)

* Actual energy saving :
64.595 kWh/year (116 kWh/m2/year) **45%**

* Energy saving "promised" according to EU-application/contract :
40.515 kWh/year (73 kWh/m2/year or **28%**

In addition and due to better routines and installed heat control equipment, travels for the church caretaker are reduced by the equivalent of approximately *255 liters of petrol (half a ton / 500kilos) of CO_2 every year.*

4.6. Data analysis

4.6.1. Energy consumption

1.1.6.1. Energy Demand: Electricity

In Norway electricity is produced from local hydropower and is used even for heating of this building through resistance heaters.

	[kWh/m^{2}a]	Total annual (kWh)
Total electricity (hydropower)	141	78 040
Electricity consumed by heating	119	66 334
Electricity consumed for lighting etc	22	11 706
Primary Energy (Total electricity)	141	78 040

1.1.6.2. Contribution from Renewables

	Total annual [kWh]	Renewable fraction
Solar Thermal	2 000	0.03
PV (fans running solar thermal syst.)	300	0.025

4.6.2. Thermal comfort

2.1.6.1. Reported on basis of users satisfaction enquiry

An "overall user satisfaction survey" was carried out. A two page user survey was distributed to the regular Sunday church service goers during the winter of 2006/2007. It highlighted the comfort and energy issues through the following summing up question :
- Have you noticed improvements in the indoor climate since last winter as regards draught, temperature etc.
From the returned forms the following responses were drawn :

- Much better 55 %
- A little better 35 %
- No improvement 10 %

4.7. Summary

4.7.1. Foreseen and Obtained Energy saving

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, heating (heating is 85% of total energy need.)	63	119	35 115	54 906

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, electricity (lights etc is 15 %.)	10	22	5 400	9 689

At Hol church all bought energy used is produced at a local hydropower station owned by the local electric energy utility.

4.7.2. Overall energy consumption

	Before retrofit	After Retrofit Foreseen	Saved foreseen	After Retrofit Measured	Saved measured
Primary Energy [kWh/m^{2}a]	257	184	73	141	116

4.7.3. Overall Economic evaluation

Total extra costs (Foreseen) [EUR]	Total extra costs (Observed) [EUR]	Saving (Foreseen) [EUR/a]	Saving (Observed) [EUR/a]	Payback Foreseen [a]	Payback Observed [a]
136 700	51 000	6 100	9 689	22	5

Energy costs used for calculation (2008). See also lessons learnt (below) :

Thermal (€/kWh)	0,15
Electric (€/kWh)	0,15

4.7.4. Climate data – degree days.

The data for the church before retrofit were from 2002.
Degree days from 2002 for six stations in the Hol region show the figure 5 620.
Degree days for year 2007 for the same stations (average) show the figure 5 860.
The monitoring year degree days after retrofit is almost 5 % higher than before retrofit.
The results of the project are therefore 5% better than the figures above show.

4.8. Lessons learned

- Existing, listed buildings are part of an architectural heritage that is well protected by the state through Antiquarian Authorities. They have an important job at protecting the valuable listed buildings and groups of buildings. This important job often is in conflict with the equally important job of reducing the energy need in existing buildings.

- The processes described above are time- and resource demanding. One should be prepared for several rounds before an approval is possible – if ever.
- In this instance, had it not been for the Bishop overruling the AA, there would have been no solar thermal system.
- A motivated client and a motivated caretaker is a crucial element towards success.
- Awareness building with the caretaker is showing positive energy need reducing results.
- As the project developed the local energy utility Ustekveikja decided, contrary to our predictions, that the cost of electricity shall fall instead of rise. Whilst the electricity costs in Norway have risen over the last years and is now in the region of our predictions that is being used for our payback period calculations, Ustekveikja have reduced the costs of electricity down from E 0,15 to between 1/2 to 1/3 of the average market price in the winter, for the inhabitants in the region, as a gesture to them. Through this, Ustekveikja argues that the inhabitants in this way get their share of the valuable local hydropower plants.
  This undermines energy efficiency measures and the introduction of renewable energy as the savings are reduced and payback time increases. It is also contrary to the trends in all other parts of Europe and of Norway.
- PV (solar electricity) is normally more costly per m^2 installed modules compared to solar thermal. One m^2 PV also delivers only 1/3 of the energy delivered by the same m^2 solar thermal. PV payback time is so long that it brings up the overall payback time for the total building project to an unnecessary high level.

5. Prøvehallen

Author: Ove Mørck

5.1. General data

5.1.1. General information

Year of construction: 1930
Year of renovation (start): 2004
Number of storeys: Originally: 1, after renovation: 3

Heated volume (m³): Gross heated volume (including external walls) = 15,700 m^3
Cubic contents, volume (m³): Net volume (excluding external walls) = 13,700 m^3
Gross area (m²): Gross area including external walls = 770 m².
Living area (m²): 712 m²
Floor area (space) (m²): 1809 m²

Table 1: Total treated floor area (including external wall)

Ground floor	770 m2
2. floor	398 m2
3. floor	640 m2
Total	1809 m2

Total floor area (m^2): Originally: 765 m²,
Window/glass areas (m^2): 220 m^2

5.1.2. Site

The site is located in an urban area called Valby located in Copenhagen. The site is an old industrial area, that is being completely reshaped, modernised and made into a new neighbourhood with its own identity including the building Ovnhallen (see below) renovated into a modern school and Proevehallen which will be a public cultural centre.

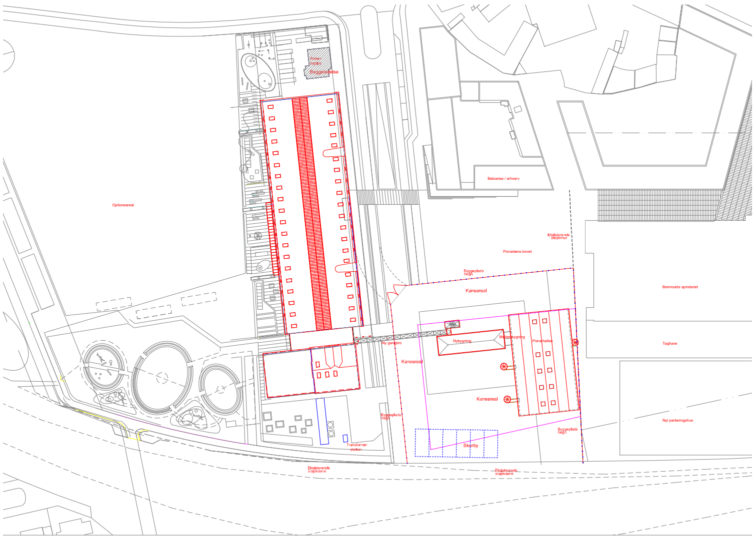


Fig. 5.1 The building site. Ovnhallen (to the left) and Proevehallen.

Copenhagen is the capital of Denmark, latitude: 55.4°N., longitude: 12.4°E, Altitude: 50 m. Temperate coastal climate. Mean annual temperature: 8 °C, mean winter temperature: 4 °C.

5.1.3. Building type

The building, Proevehallen ("The test hall") was together with the building, Ovnhallen, right next to it, part of an industrial complex - a porcelain fabric. In Ovnhallen the porcelain was manufactured and in Proevehallen porcelain-isolators for the high voltage electricity distribution lines were tested. Proevehallen is an old open hall building constructed in 1930'ies in 1 floor. However the height of the building was the same as that of a 5 floor building. See photos below.

Fig, 5.2 Proevehallen, seen from railway

Fig. 5.3. Ovnhallen – being retrofitted.

5.2. Before retrofit

5.2.1. Building construction

Proevehallen had not been used for a number of years. It was an empty hall with only a ground floor in spite of a height of 18 m. Because of its original purpose it had been built as a minimal construction with no insulation in walls and windows and simple single glass metal frame windows. In the renovation process 2 new floors had to be fitted in, and insulation and new windows had to be installed. The building had been unheated and ventilated solely by the port opening and the windows, so also complete heating and ventilation systems had to be designed and installed. As there was no energy consumption before retrofit to compare to the energy saving design had to compare to the existing requirements in the Danish building regulations and estimate the savings compared to a building renovated to these requirements. Complying with the requirements in the building regulations was not a requirement for the renovation as it was valid only for new buildings.

There was no existing drawings available for the project. Below the two photos show the state of the building before retrofit.

Fig. 5.4 and 5.5. Proevehallen before the retrofit process started.

5.2.2. Existing heating, ventilation, cooling, lighting systems

There was no heating nor cooling system and the building was ventilated by the large port opening and the windows. Lighting was simple incandescent light fixtures in the ceiling.

5.2.3. Energy and water use

The building had not been in use for several years, so no information could be obtained on previous energy and water use.

5.2.4. User satisfaction before retrofit

The building had not been in use for several years, so no information could be obtained on user satisfaction before retrofit.

5.3. Energy saving concepts

The energy saving targets was reached by implementing an integrated concept for energy savings and renewable energy utilisation. The energy savings were achieved by additional insulation of the external enclosure of the buildings, low-energy windows and demand controlled mechanical and natural ventilation. Renewable energy is utilised in two systems:

An array of Photovoltaic cells on the south gable wall and an innovative Photovoltaic/Thermal (PV/T) solar collector that will be cooled by a heat pump and the heat delivered to the heating plant of Proevehallen.

5.3.1. Building construction

Originally it was the intention to insulate the external walls on the inside to keep the architectural expression of the buildings old brick walls. However, it turned out that for fire protection reasons (law and regulations) this would require quite substantial and extremely costly treatments of the metal beam load supporting parts of the wall. Therefore it was decided to insulate the wall externally. This has not economical consequences to the project and from a technical point of view it is a clear advantage, as it is well known that external insulation is better at preventing thermal bridges than internal insulation.

Table 2: Building construction data

	Pre retrofit U-value [w/m^2]	Post retrofit U-value [w/m^2]
Walls	1.6	0,18
Roof	3.1	0,13
Windows	6.0	1,56
Doors	6.0	1,56

5.3.2. Heating

The basic heating system selected for Proevehallen is a standard hydronic radiator system. This is not a special energy saving measure of the project, so standard procedures for sizing the radiators, piping, pumps, etc. have been used. The piping has been isolated according to Danish standard specifications. The air supply in the mechanical ventilation system is preheated - if needed - by a heating coil. This is supplied also from the hydronic system. The monitoring of the heating energy consumption also include this consumption.

5.3.3. Ventilation

The building is ventilated by a combination of natural ventilation – of the upper floor – and mechanical ventilation of the lower floors which includes bathroom and toilets. The upper parts of the high windows are used for natural ventilation of the upper floor. As the openings are placed high above the ceiling the incoming air will be mixed with the indoor air – thus reducing the risks for cold draughts. This ventilation will be required only when the gym on the upper floor is used by people generating heat which has to vented out, so preheating and heat recovery is not needed for this air exchange. The windows will be demand-controlled according to CO_2 and temperature.

An efficient air-to-air heat exchanger is used for the mechanically ventilated part of the building. This balanced ventilation system keeps a minimum low ventilation for the toilets and supply additional ventilation when the CO2, humidity (in the bathrooms) and temperature sensors calls show that there is a demand for additional air exchange.

Based on the use of the naturally ventilated upper floor and the efficient heat exchanger in the mechanical ventilation system the solar preheating of air could not be economically justified. The benefit and costs of solar preheating of ventilation air had not been explicitly calculated and shown in the original proposal, so this modification does not mean any changes for these calculations.

5.3.4. Solar PV & Solar PV/Thermal (PV/T)

In the original proposal a 25 KWp PV array was to be mounted on the roof of Proevehallen. In the design phase it turned out that the roof was constructed as a so-called “minimal-construction" and could not take the additional weight of the PV-array. Therefore it was decided to place the array on the south gable wall – however here was (with the artist design – see below) only space enough for 19 kWp PV arrays. Therefore a combined solar collector/ solar cell panel was planned in stead of the originally intended solar heating system and the remaining part of the PV array (6 out of 25 kWp) placed here.

5.3.5. BEMS

A Building Energy Management System (BEMS) has been designed and installed to control the heating and ventilation systems. This will assure optimal control of the building and thus save energy compared to simpler or manual control systems.

The BEMS system will also be used to capture energy consumptions and data for temperature, CO2, humidity plus external weather conditions that can be used for analysis with respect to indoor comfort, air quality and energy consumptions.

5.3.6. Predicted energy savings

Energy saving measures, heating, cooling, ventilation	[kWh/m^{2}a]	Total [kWh/a]
High efficient ventilation	47,2	118000
Improved insulation of façade and roof	6,0	15000
Low-e windows	8,0	20000
Heating energy savings (lower water use)	9,2	23000
BEMS	12,0	30000
Combined PV and Thermal heating system	6,6	16500
Total heating energy savings	**89,0**	**222,500**

Energy saving measures, electricity	[kWh/m^{2}a]	Total [kWh/a]
High efficient fans in the ventilation	12,4	31000
BEMS	4,0	10000
Electrical output of PV/T cells	2,4	6000
PV-cells, 19 kWp	6,4	16000
Total electricity energy savings	**25,2**	**63,000**

Water saving measures	[m^3/m^{2}a]	Total [kWh/a]
Water savings (toilets, showers, taps)	0,25	625
Total water savings	**0,25**	**625**

5.3.7. Predicted costs and payback

Energy saving measure/investment	Total costs [EUR]	Saving [EUR/a]	Pay-back periods [a]
High efficient ventilation	33.557	8.870	3,8
Improved insulation	60.403	1.128	53,6
Low-e windows	26.376	1.503	17,5
Heat savings (water use)	6.711	1.729	3,9
BEMS (heating savings)	20.134	2.255	8,9
PV/T w. HP - thermal + electrical	102.500	2.595	39,5
High efficient fans	13.423	5.326	2,5
BEMS (el. savings)	20.134	1.718	11,7
PV-cells, 19 kWp	136.800	3.351	40,8
Water savings	6.711	2.148	3,1
Total	**426.749**	**30.623**	**13,9**

Energy costs used for the payback calculation (2004):
Thermal : 0,075 Euro/kWh (0,55 DKK/kWh)
Electric: 0,21 Euro/kWh (1,55 DKK/kWh)

The cost for the additional bearings for the PV-panels on the gable wall was 2119 euro/kWp. The cost will be further increased because of artwork placing of the PV-panels. These additional costs are not included in the cost presented in the table – as they include other expenses, for example the fee to the artist. Furthermore this solution requires the use of new, totally black solar cells, at a higher cost than conventional solar cells.

5.4. Life cycle assessment

5.4.1. Brief Description of the retrofit action

The site is an old industrial area that is being completely reshaped and modernised. The roof and external walls have been insulated, new and better performance windows have been designed, heating and ventilation systems have been renovated, and solar PV and solar PV/thermal systems have been installed.

Primary energy saving and emissions			
Primary energy save (E_{year})	8 174 459.0		[kWh]
Global Emission saving (EM_{S-i})	1 724.3		[$ton_{CO2\ eq.}$]

Summary of materials employed and main components			
Component			
Brick	377.4		[ton]
Plaster	109.2		[ton]
Wooden floor	11.6		[ton]
Felt roofing	9.8		[ton]
Mineral wool	5.3		[ton]
Steel	3.4		[ton]
Concrete	30.8		[m^3]
Energy saving lamps	1.7		[kW]
High efficient windows	180.0		[m^2]
Solar PV and solar PV/thermal plants	225.0		[m^2]
Heat pump	6.0		[kW]

Energy and Environmental Indexes			
Global Energy Requirements (GER)	914 888.0		[kWh]
Global Warming Potential (GWP)	180.0		[ton $CO_{2\text{-Eq.}}$]
Nutrification Potential (NP)	91.0		[kg PO_4]
Acidification Potential (AP)	802.0		[kg SO_2]
Ozone Depletion Potential (ODP)	0.02		[kg CFC_{11}]
Photochemical Ozone Creation Potential (POCP)	297.0		[kg C_2H_4]

Synthesis Indexes			
Energy Payback Time ($E_{\text{-PT}}$)	1.3		[year]
Emission Payback Time ($EM_{\text{-PT}}$)	1.1		[year]
Energy Return Ratio (E_R)	8.9		

Contributors to data survey:	Dr. Ove Mørck
Life Cycle Analyst:	Fulvio Ardente

5.5. Construction phase description

5.5.1. Building construction

Figure 6 shows a cross section of Proevahallen. The energy saving concept included additional insulation of the building envelope and new low-energy windows.

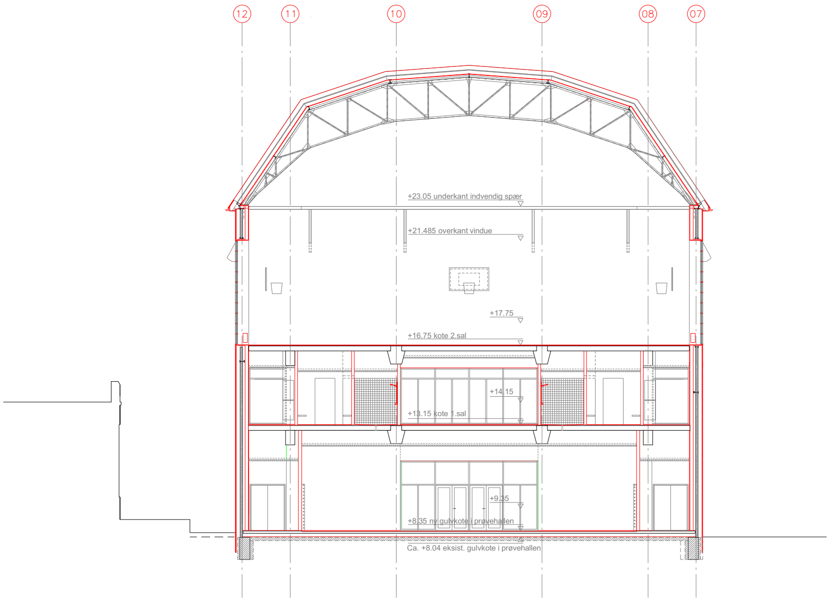


Fig. 5.6. Cross section of the renovated Prøvehallen.

5.5.1.1 Roof

As stated above the roof was a so-called minimal construction – meaning that its load bearing capacity was very limited. It turned out that it could hardly carry the weight of the insulation according to the requirements in the building regulations, so an additional 10 cm as required by the BRITa-in-PuBs project would require costly construction strengthening, which would be out of the question. So, this part was almost given up, when the project architect suddenly came to think of the fact that most part of the roof was already strengthened because of a large crane that was hanging from the roof to move the isolators to be tested. This meant that only a small part of the roof had to be strengthened and thus the BRITA-in-PuBs requirements could be carried through. The resulting U-value of the roof is 0,13 W/m²K compared to 0,2 W/m²K which is required in the Danish Building Regulations. For a detail see fig.5.7.

5.5.1.2 Walls

As stated above the external walls had to be insulated on the outside. This did not create any additional problems. The following U-value was specified: 0,18 W/m²K – the corresponding requirement in the Danish Building Regulations is 0,4 W/m²K. Fig. 5.7 below shows the details of roof and wall insulation.

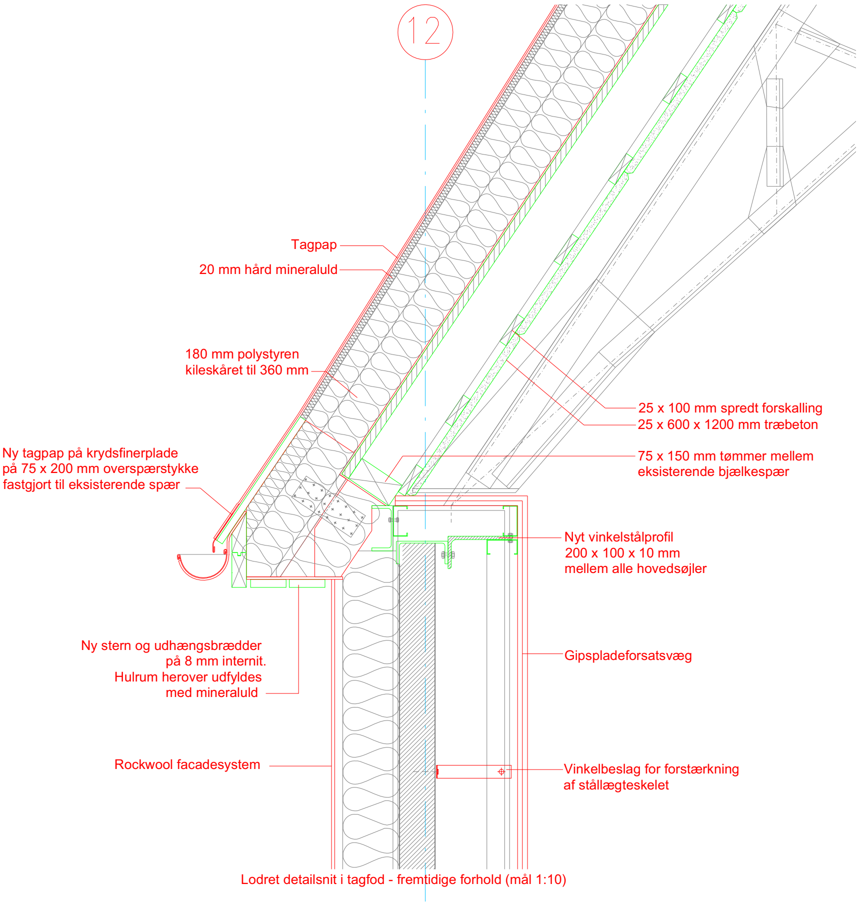


Fig. 5.7. Cross section of wall and roof construction details.

5.5.1.3 Windows

The new windows had to be designed in the same way (with the same look) as the existing windows. This meant that the subdivision of the larger windows had to have the same shape and size as before. The size of these are approximately 30 x 42 cm^2. The main part of the design process was therefore to search for a window product that both aesthetically and thermally could live up to the requirements. The system selected is from a renowned Danish company called HS Hansen – generally they are very expensive, but they gave a special offer and won the order. With a center U-value of the glazing of 1,1 W/m^2K the overall U-value of the windows became 1,56 W/m^2K. What is required in the Danish Building Regulations is 1,8 W/m^2K.

5.5.2 Heating

The design of the heating system was straightforward – the additional feature was the control of the system by the BEMS system.

5.5.3 Ventilation

The ventilation system is described under 5.3.3 above. Strategies for the demand controlled ventilation had to be worked out for both the naturally ventilated parts and the mechanical ventilated part. The mechanical ventilation system was designed under both a cost constraint and a requirement agreed to by the design team, that it should be reliable, and easy to maintain, which meant that it could not be too complicated in layout. The design work of the mechanical ventilation system also included the ventilation unit suitable for the BEMS system control.

5.5.4 Solar PV & Solar PV/Thermal (PV/T)

As explained in paragraph 5.3.4 above the originally planned PV system on the roof had to be replaced by a PV-system on the gable wall and a PV/T system where the PV/T collectors are placed on a neighbour building. The systems are described below.

5.5.5 Solar PV/Thermal (PV/T)

6 kWp of PVT are placed on the roof of an adjacent building –as where the solar collectors originally planned for. They will be placed towards south with an optimal slope of 40-45 degrees from horizontal.

The solar collectors are cooled by a heat pump and the heat delivered to the heating plant of Proevehallen. The idea of the solar energy system for DHW for Proevehallen is to utilise an innovative Photovoltaic/Thermal (PV/T) solar collector which both produces electricity and heat. A PV/T component, developed by the Danish PV company Racell was mounted by the solar heating company Batec Solar Heating, see fig. 5.8.

Fig. 5.8. Photo of PV/T solar collector – and of the collectors mounted on the roof.

The efficiency of the PV – cells in dependence of different absorber temperatures are accounted for in the appendix: SE123W-PVT-Thermal-module-data.pdf. In this document is also -accounted for the thermal efficiency of the PVT – panels working as solar collectors.

Prior to the demonstration of the PV/T system at Proevehallen development work has been carried out in a Danish RTD project, named “PV-Optiroof”. The basic idea in this project was to utilise a PV/T solar collector absorber without a glazing system and combine this with the operation of a heat pump which cools the PV/T array and transfers the heat to produce DHW. This means that the typical operation temperature of the PV/T absorber and the solar cell will be around 5-10°C. This temperature range shall be compared to normal operation conditions of unglazed solar cells which will often be around 40°C.

With the stated temperature influence on the electrical output of 0.44% per °C and operation temperature of the PV/T solar cells of 10°C this will mean an extra solar electricity production of 0.44 x 30 = 13%, while for the 5°C operation temperature it is an additional 15%. At the same time a quite high solar thermal yield will be obtained due to the near ambient operation temperature.
The PV cells are connecting according to the Danish net-metering system, which means that the electricity production by the PV cells will first be used in the building and if it exceeds the demand of the building it is send to the grid. In this way the cells are integrated in the overall energy management of the building.

A high efficiency heat pump will be used to take heat out of the PV/T solar collectors and then transfer the heat into DHW heating boiler for Proevehallen (see Fig. 5.9). The proposed system has gained support and interest from both the local energy company, Copenhagen Energy and the electricity production controller Elkraft System. This is due to the fact that there exist problems in Denmark concerning electricity surplus production in winter, and here heat pumps in combination with renewable energy systems are seen as a very interesting option with a considerable potential for replication.

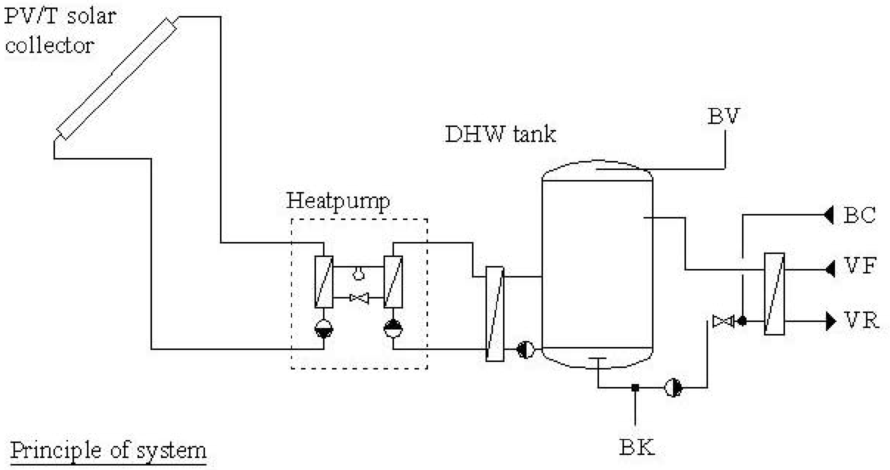


Fig. 5.9. Sketch of PV/T heat pump assisted energy system for DHW-production.

Compared to individual PV and solar DHW systems there are cost savings on the combined use of a PV/T system, but the overall payback is more or less the same. However, one of the interesting aspect is that although the heat pump uses electricity for its operation, this can be covered by the PV electricity production – in this case considering the electrical output of 1.25 kWp of the PV array a completely CO2 neutral DHW solution on a yearly basis will be the result.

5.5.6 Solar PV

As mentioned above the main part of the solar cells was shifted to the south gable wall. The additional bearing for the solar cells was mounted while the external insulation was added and is already in place. This was necessary to allow the mounting on the existing wall – these bearings are used for the normal mounting system of the cells. Furthermore the gable solution makes the solar cells more visible – as explained: the gable can be seen from the local subway-train which passes close by and everyday transports 400.000 of people to and from work.

It has therefore been necessary to get acceptance from the Chief Architect of Copenhagen, who has agreed on the condition that the integrated solution for the placement of the solar cells proposed by the artist is carried out. This means that the project will get a “light-house effect” for PV-cells in Denmark.

Fig. 5.10 Mounting racks for the PV-panels on the south gable wall

Fig. 5.11 The artist design of the PV panels on the gable wall.

5.5.7 BEMS

The specifications for the BEMS systems were worked out by the consultant. Then these were transferred into an implementation document by the company that delivered the system – TAC A/S – the details were clarified i.e. sensor locations and control algorithms. The type and location of the onsite display was discussed and agreed to – and the capabilities and limitations of these (in principle it provided access to the internet, but it was not the intentions that the project should provide that). The main feature of the TAC system and also a main reason for selecting this system is that the system is accessible anywhere from the internet.

The screen dumps shown in the figures 5.12-14 illustrate the user interface of the system.

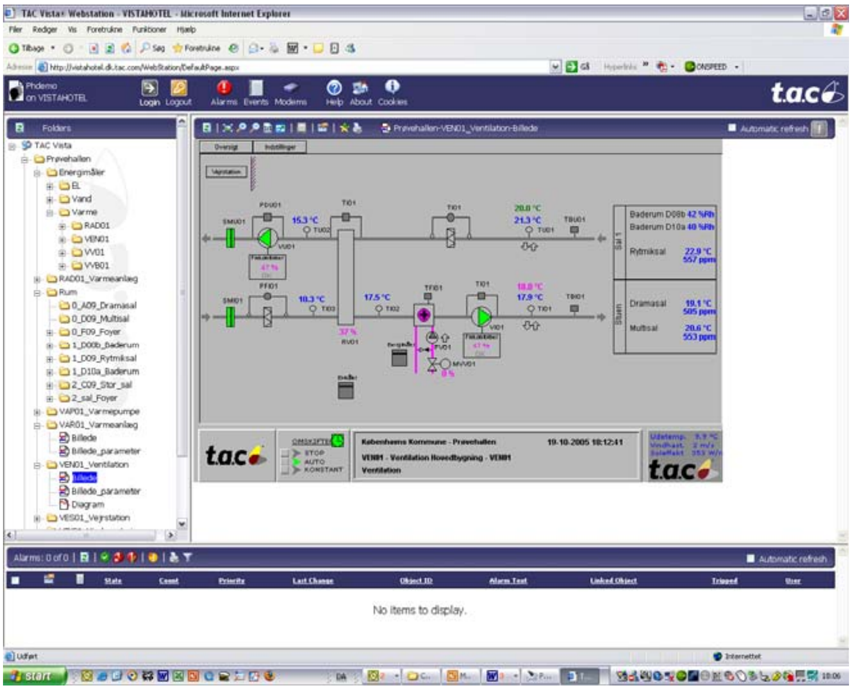


Fig. 5.12 Screen dump from BEMS system showing part of the ventilation control setup

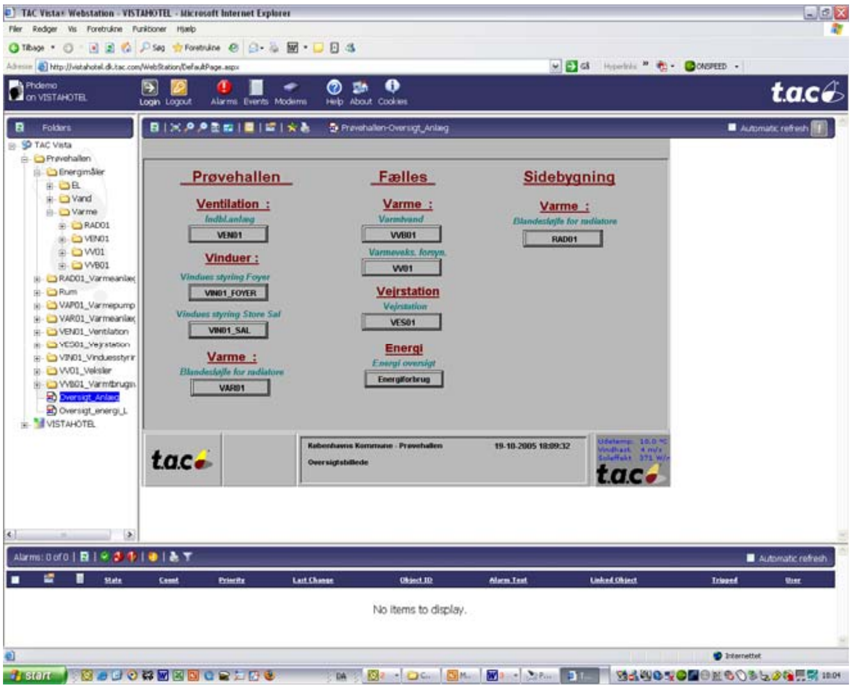


Fig. 5.13 BEMS screen dump – overview screen for entering into different parts of the BEMS

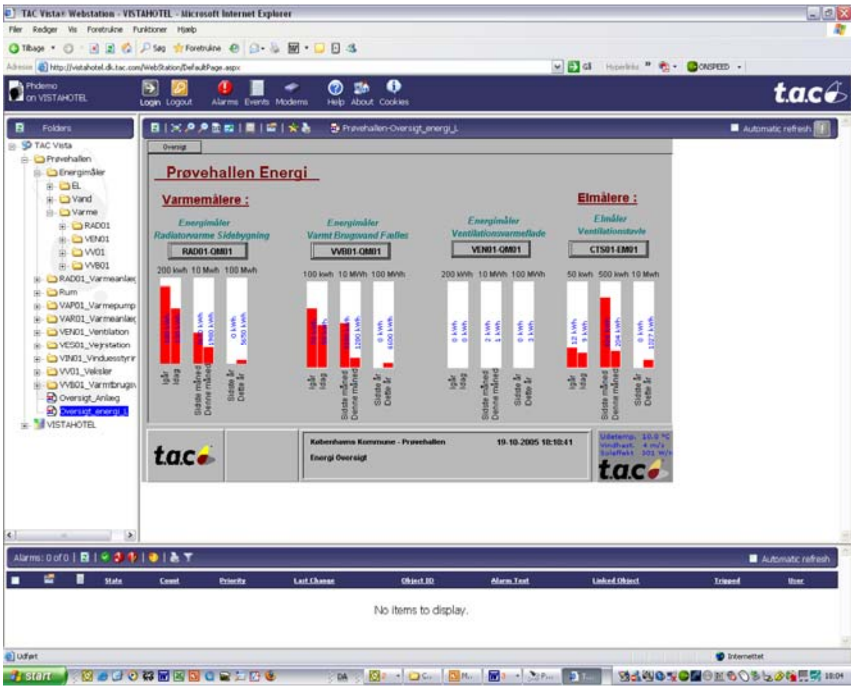


Fig.5.14 BEMS screen dump – showing a metering presentation.

5.5.8 Water savings

Photo: Water saving showers.

Water savings were obtained by using water saving taps and toilets - besides new, very reliable and robust water saving showers were chosen for the bathrooms. See photo to the left.

5.6 Monitoring

5.6.1 Monitoring plan

The monitoring is included in the BEMS system. The following parameters are monitored:

- Thermal Energy (see diagram)
  - Total district heating (for the main building)
  - Radiators (VAR01)
  - Hot water (VVB01)
  - Ventilation air preheat (VEN01)

- Electrical Energy
  - Total electricity
  - Ventilation system (fans)

- Water
  - Total water
  - Domestic hot water

- Renewable Contribution
  - Electricity produced by PV and PV/T

- Control parameters
  - Flow temperature
  - Inlet supply temperature

- Local Weather

  The local weather is monitored on site and includes the following parameters
  - Temperature
  - Precipitation
  - Solar Radiation
  - Wind speed
  - Wind direction

- Thermal Comfort
  - Indoor temperature (six rooms)

- Indoor Air Quality
  - CO_2 (rooms with natural ventilation)

- The measurements are taken on site.
- The measurements are taken continually during the whole operation period.
- The measurements will continue after the monitoring period.
- The logging interval is every 10 second and the stored interval is nor the same for all parameters. The stored interval is between 10 min and one day.

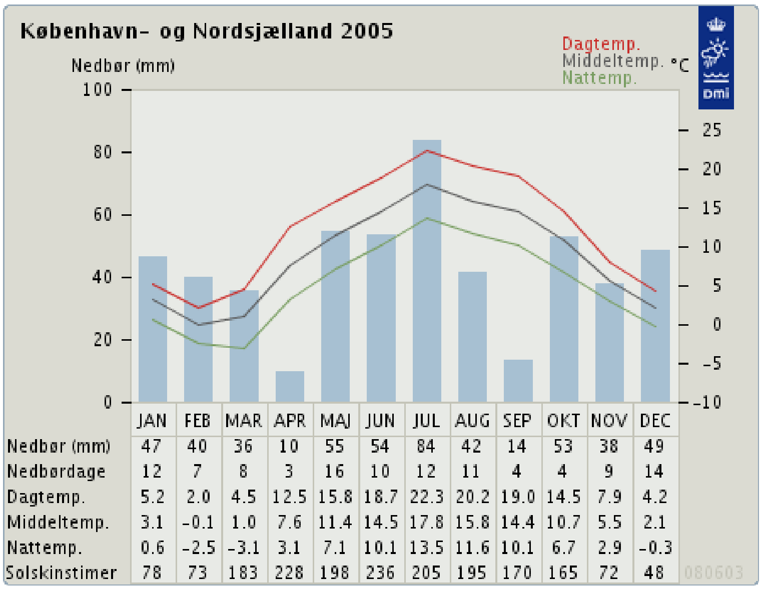
5.7 Data analysis

5.7.1 Local Weather

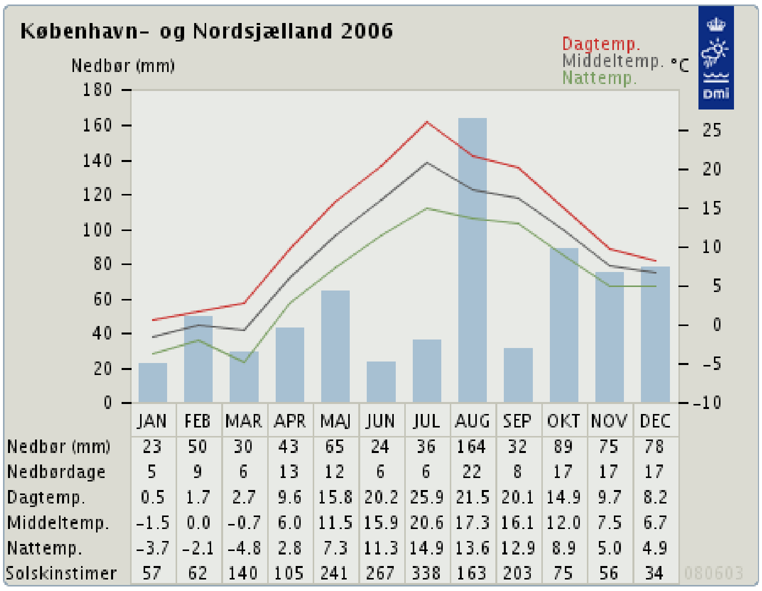
The monitored weather data are compared to weather data from the nearby weather station

The following data are downloaded from the website of the Danish Meteorological Institute (DMI). It is monitored data from the last four years obtained from the region of Copenhagen and North Zealand.

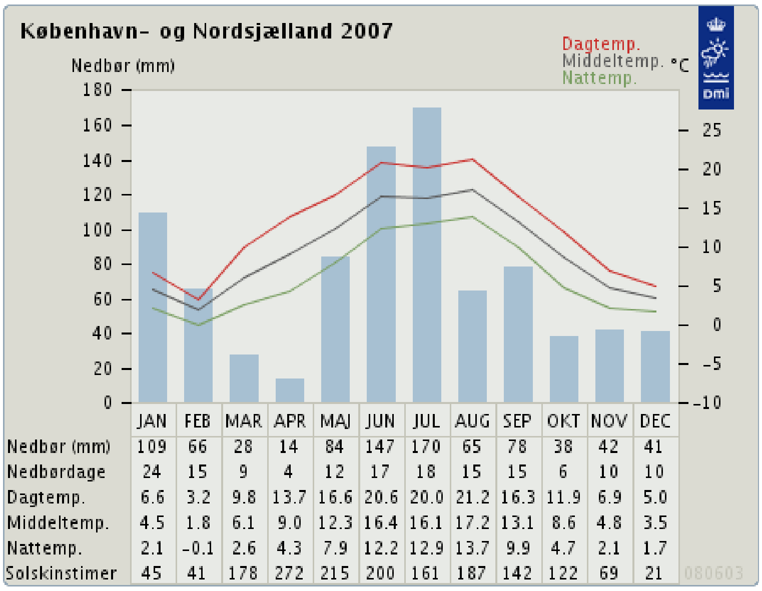
Nedbør (mm):	precipitation
Nedbørdage:	days with rain
Dagtemp:	average temperature during daytime
Middeltemp.:	average temperature
Nattemp.:	average temperature during night time
Solskinstimer:	number of sunshine hours



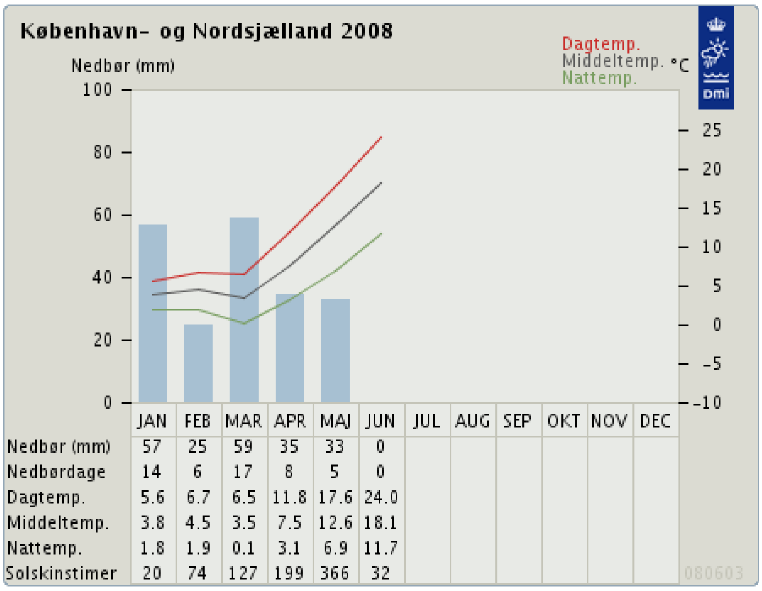
	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Nedbør (mm)	47	40	36	10	55	54	84	42	14	53	38	49
Nedbørdage	12	7	8	3	16	10	12	11	4	4	9	14
Dagtemp.	5.2	2.0	4.5	12.5	15.8	18.7	22.3	20.2	19.0	14.5	7.9	4.2
Middeltemp.	3.1	-0.1	1.0	7.6	11.4	14.5	17.8	15.8	14.4	10.7	5.5	2.1
Nattemp.	0.6	-2.5	-3.1	3.1	7.1	10.1	13.5	11.6	10.1	6.7	2.9	-0.3
Solskinstimer	78	73	183	228	198	236	205	195	170	165	72	48



	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Nedbør (mm)	23	50	30	43	65	24	36	164	32	89	75	78
Nedbørdage	5	9	6	13	12	6	6	22	8	17	17	17
Dagtemp.	0.5	1.7	2.7	9.6	15.8	20.2	25.9	21.5	20.1	14.9	9.7	8.2
Middeltemp.	-1.5	0.0	-0.7	6.0	11.5	15.9	20.6	17.3	16.1	12.0	7.5	6.7
Nattemp.	-3.7	-2.1	-4.8	2.8	7.3	11.3	14.9	13.6	12.9	8.9	5.0	4.9
Solskinstimer	57	62	140	105	241	267	338	163	203	75	56	34



	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Nedbør (mm)	109	66	28	14	84	147	170	65	78	38	42	41
Nedbørdage	24	15	9	4	12	17	18	15	15	6	10	10
Dagtemp.	6.6	3.2	9.8	13.7	16.6	20.6	20.0	21.2	16.3	11.9	6.9	5.0
Middeltemp.	4.5	1.8	6.1	9.0	12.3	16.4	16.1	17.2	13.1	8.6	4.8	3.5
Nattemp.	2.1	-0.1	2.6	4.3	7.9	12.2	12.9	13.7	9.9	4.7	2.1	1.7
Solskinstimer	45	41	178	272	215	200	161	187	142	122	69	21



	JAN	FEB	MAR	APR	MAJ	JUN	JUL	AUG	SEP	OKT	NOV	DEC
Nedbør (mm)	57	25	59	35	33	0						
Nedbørdage	14	6	17	8	5	0						
Dagtemp.	5.6	6.7	6.5	11.8	17.6	24.0						
Middeltemp.	3.8	4.5	3.5	7.5	12.6	18.1						
Nattemp.	1.8	1.9	0.1	3.1	6.9	11.7						
Solskinstimer	20	74	127	199	366	32						

A comparison between monitored data and data from DMI are shown in the table below. The monitored average temperature is a little bit higher than data from DMI. The night temperature is higher and the day temperature is lower. The normaliazation of the heat consumption is based on degree day from DMI.

Table 3: Monoitored data and data from the Danish Meterologigal Institut (year 2006).

	Average temperature		night temperature		day temperature	
	BEMS	DMI	BEMS	DMI	BEMS	DMI
May	12.8	11.5	11.4	7.3	14.1	15.8
June	17.5	15.9	15.9	11.3	19.0	20.2
July	22.4	20.6	20.8	14.9	24.0	25.9
August	18.2	17.3	17.1	13.6	19.3	21.5
September	16.7	16.1	15.6	12.9	17.9	20.1
October	12.6	12.0	12.0	8.9	13.3	14.9

The heating degree days (HDD) from DMI are given in the figure below. The actual degree days (Otober 2006/September 2007) monitored on a nearby meterological weather station is 2445 and the average heating degree day during the last 15 years on the same location is

3215. The data are downloaded from the website of the Danish Meteorological Institute. The HDD during the monitored period had been lower compared with an average year and then the monitored energy consumption for space heating is lower compared with a normal year.

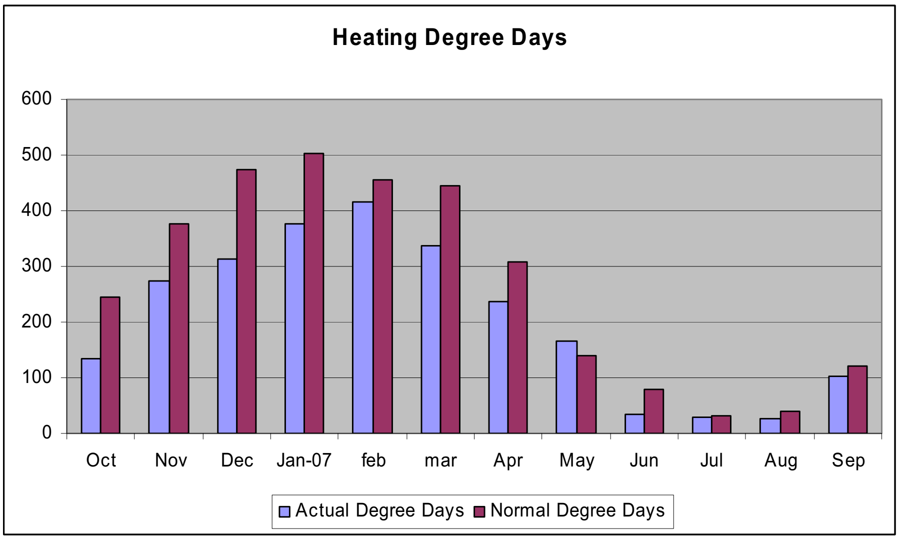


Figure 5.15: Monthly heating degree day from DMI obtained from October 2006 to September 2007.

5.7.2 Energy and water consumption

5.7.2.1 Energy Demand: Electricity

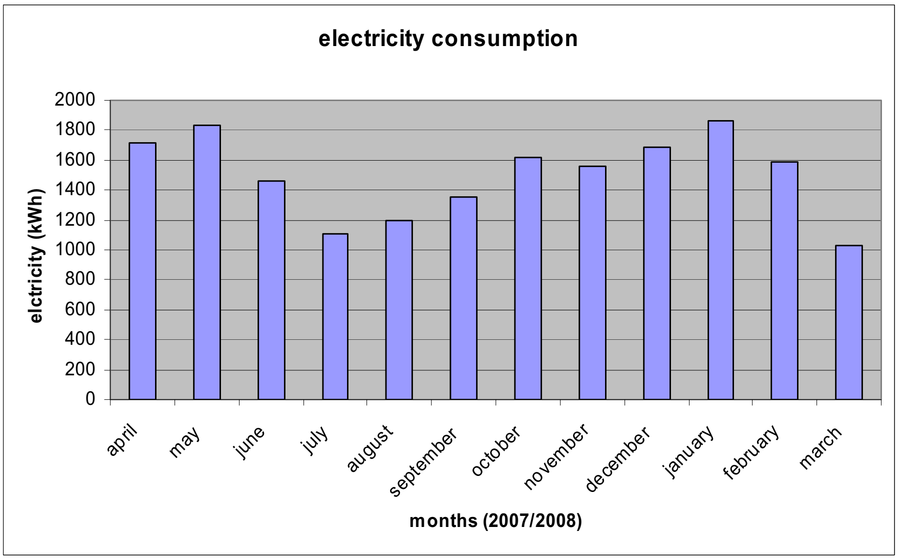


Figure 5.16: Total electricity consumption month by month.

	[kWh/m^{2}a]	Total annual (kWh)
Total electricity	70.3	127,000 (E1)
Electricity consumed ventilation system	3.14	5,680
Electricity consumed for lighting	67.16	121,320
Primary Energy (Total electricity x 2,5)	175.75	317,500

The national benchmark for electricity is 62.7 kWh/m^2, and the predicted an electricity demand of 47,8 kWh/m^2. It was furthermore estimated at the outset that the high efficiency fans in the ventilation system and the use of the BEMS-system would reduce the electricity consumption with 16,4 kWh/m^2. This means that the measured electricity demand is 31,4 kWh/m^2 higher than expected. However, the explanation for this is straightforward: Proevehallen has become a real success as a local cultural centre of the neighborhood and it is used far more than anticipated for theater plays and concert performances, which consume high amounts of electricity for spotlights, amplifiers, etc. The very low figure for electricity consumption of the ventilation system shows that energy efficient fans are working as expected. It is more difficult to evaluate the effect of the BEMS system.

5.7.2.2 Energy Demand: Thermal

The monitored energy consumption for space heating is shown in the table below together with the heating degree days from DMI. The energy consumption is 73.420 kWh and the normalised energy consumption is 95.888 kWh.

$$\mathrm{Heat}_{\mathrm{Norm2}}=\mathrm{Heat}_{\mathrm{Mon}}/\mathrm{HDD}_{\mathrm{Actual}}*\mathrm{HDD}_{\mathrm{Average}}$$

Table 4: Monitored energy consumption for space heating and HDD from DMI.

	Actual HDD	Heat Mon.	Average HDD	Heat Norm 2
Oct-06	134	1350	246	2478
Nov	275	9140	376	12497
Dec	313	11890	474	18006
Jan-07	377	15030	503	20053
feb	416	15890	454	17341
mar	336	9720	446	12902
Apr	236	6360	309	8327
May	165	2070	139	1744
Jun	34	180	78	413
Jul	30	250	31	258
Aug	26	220	39	330
Sep-07	103	1320	120	1538
År sum	2445	73420	3215	95888

Table 5: Total energy consumption for heating (Oct-06 to Sep-07, treated floor area = 1809 m2).

	[kWh/m²a]	**Total annual (kWh)**
Space heating - monitored	40.6	73,420
Space heating – normalised (T2)	53.0	95,888
Heating energy consumed by ventilation – incl, in above	1.36	2,453
Heating energy for DHW (T3)	12.7	22,895
Primary Energy (Total thermal, PET) (T1=T2+T3)	**65.7**	**118,783**

The monitored yearly energy consumption (normalised) for space heating are shown month by month during last 12 months. It shows that the energy consumption is constantly decreasing during the last year by approximately 4000 kWh. The reason for the lower energy consumption is the constantly fine tuning of operation of energy system by the energy manager.

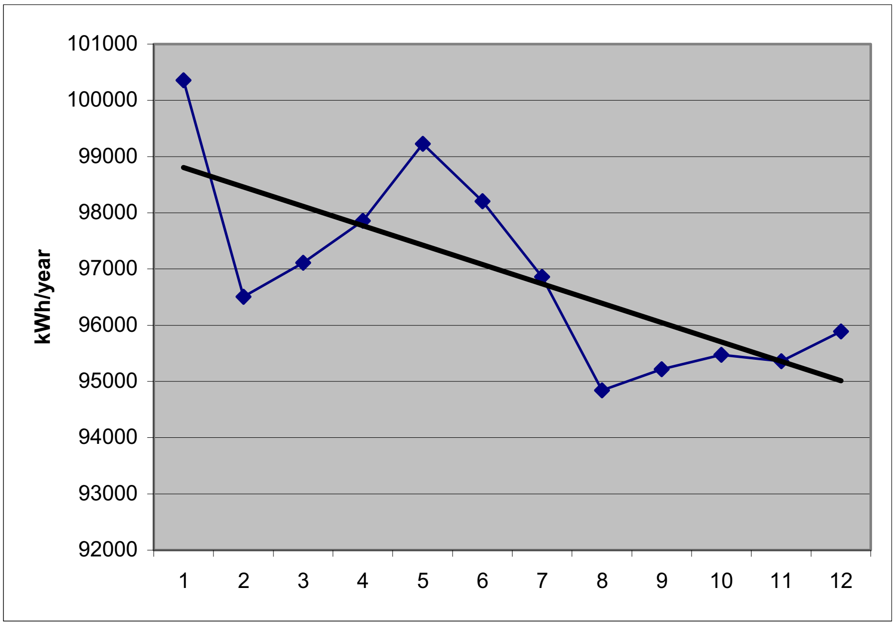


Figure 5.17: Monitored yearly energy consumption for space heating shown for the last 12 months.

The graph below shows the monitored space heating depending on the heating degree days (DMI). It shows a good correlation between energy consumption and heating degree days as the operation of the energy system efficient without unnecessary waste of energy. This perfect operation of the energy system is obtained by the building energy management system.

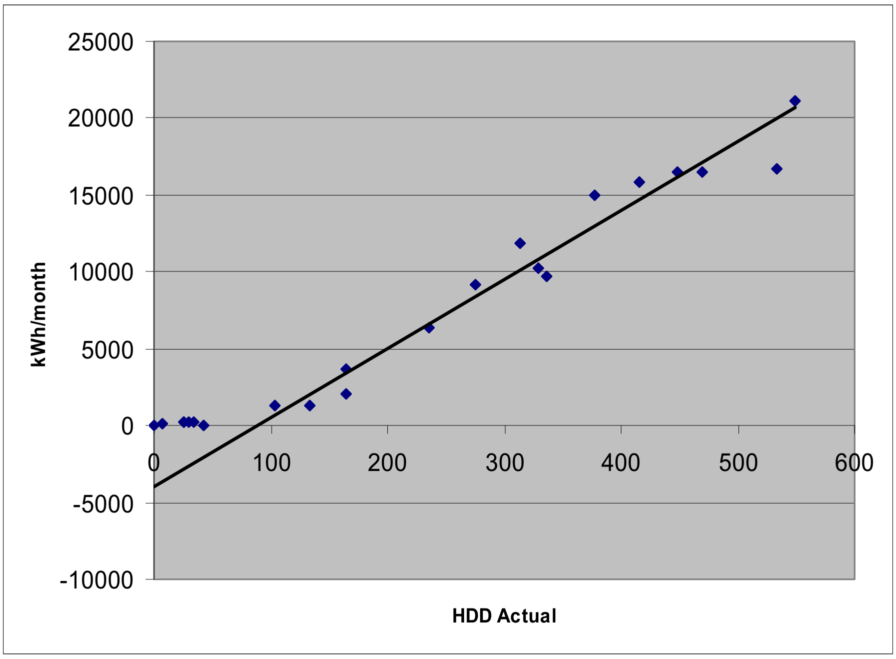


Figure 5.18: Monitored space heating depending on the HDD.

The building energy index is shown in the figure below. The reference building energy index for space is 132,0 kWh/m2 per year. The target energy index for space heating (excluding domestic hor water) is 64.8 kWh/m2 and the monitored as well as the normalised building energy index is even lower. The actual energy consumption for space heating is 18 % lower than the target.

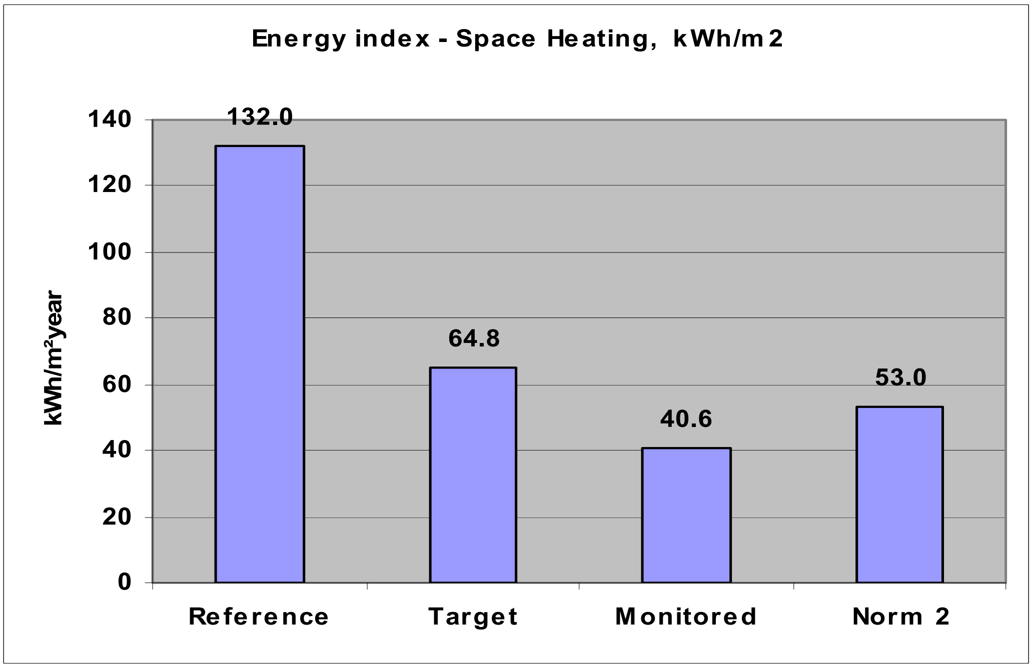


Figure 5.19: Building energy index.

5.7.2.3 Water consumption

The average hot water consumption has been 1.00 m^3/day from August 2007 until May 2008 with a slightly increase during the period.

	[m^3/m^{2}a]	Total for the whole building [m^3/a]
Water	0.20	365

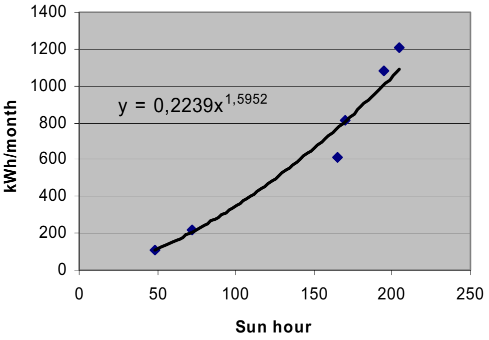
The estimated reference hot water consumption (national benchmark) is 1,13 m^3/m^{2}a and the estimated target was 0.88 m^3/m^{2}a based on estimated savings of 0,25 ^{3}/m^{2}a . That means the monitored hot water consumption is much lower than the target. The main reason for that is – according to the caretaker – that the school children do not always shower after their gym – lessons. Actually, they mostly do not. It is therefore difficult to judge whether the installed water saving measurers have worked or not.

5.7.3 Contribution from Renewables

5.7.3.1 PV/T electrical output.

The table below shows the actual metered electrical output of the PV/T cells for 6 months. Because of a data-failure only these data are currently available and the output for the remaining six months of a normalized year has therefore been estimated by using the regression curve showing the relation between PV/T electrical output and sun hours of a month. The results is 6994 kWh per normalized year.

Month	norm sun hours	actual sun hours	actual kWh	norm kWh
jan	45			97
feb	67			183
mar	110			404
apr	168			794
maj	217			1194
jun	218			1203
jul	202	205	1206	1065
aug	193	195	1078	991
sep	133	170	813	547
okt	90	165	616	293
nov	55	72	222	134
dec	42	48	105	87
Year	1540			6994



	Total annual	Renewable fraction
Solar Thermal	16500 kWh[1] (R1)	0,14 (R1/T1)
PV/T electrical output	6994 kWh (R2)	
PV	10530 kWh[2] (R3)	0,14 (R2+R3)/E1

5.7.3.2 Primary energy calculation

The primary energy calculation is in Denmark done by estimating a conversion factor of 1 for heating energy and 2.5 for electrical energy. On this basis the table below is calculated.

		Total for the whole building
Space heating	40. kWh/m^2 a	73,420 kWh/a
DHW	12.6 kWh/m^2 a	22,875 kWh/a
Electricity	178,5 kWh/m^{2}a	325,763 kWh/a

5.7.3.3 Heating system

The plan below is the heating network of Proevehallen.

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[1] The output is estimated to 330 kWh/m² as the water consumption has been to low to effectively run the heat-pump that cools the PV/T-elements.

[2] Estimated base don test results, because the actual installation of the PV was delayed due to difficulties in getting the right material for the artist's expression.

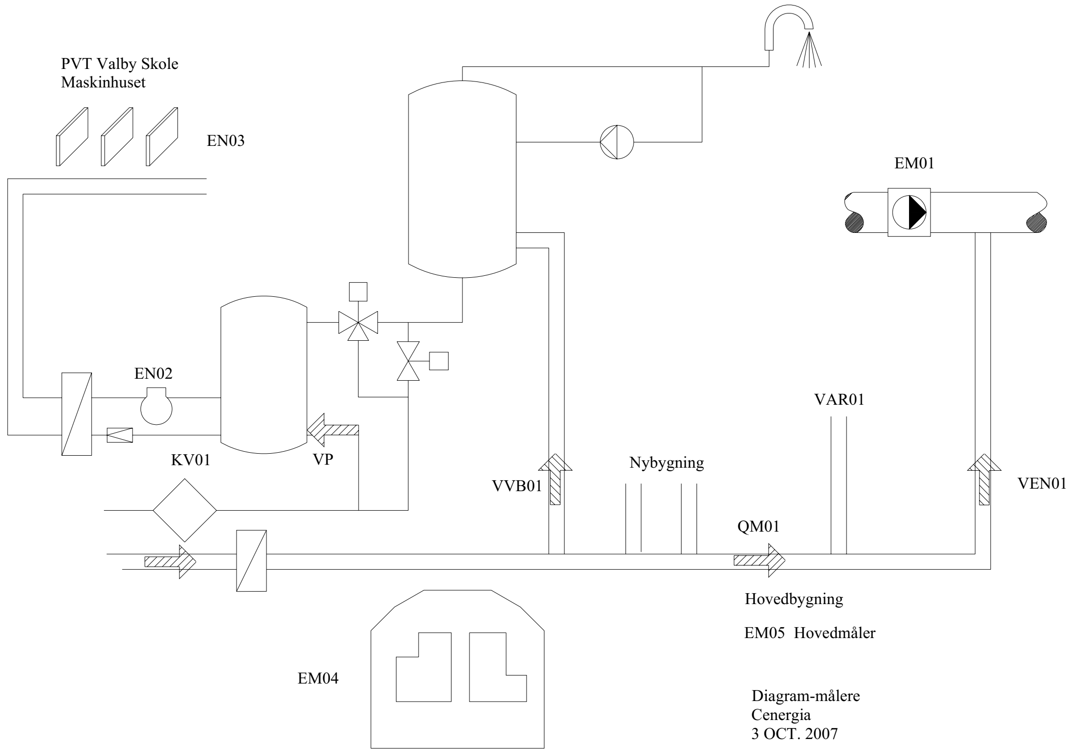
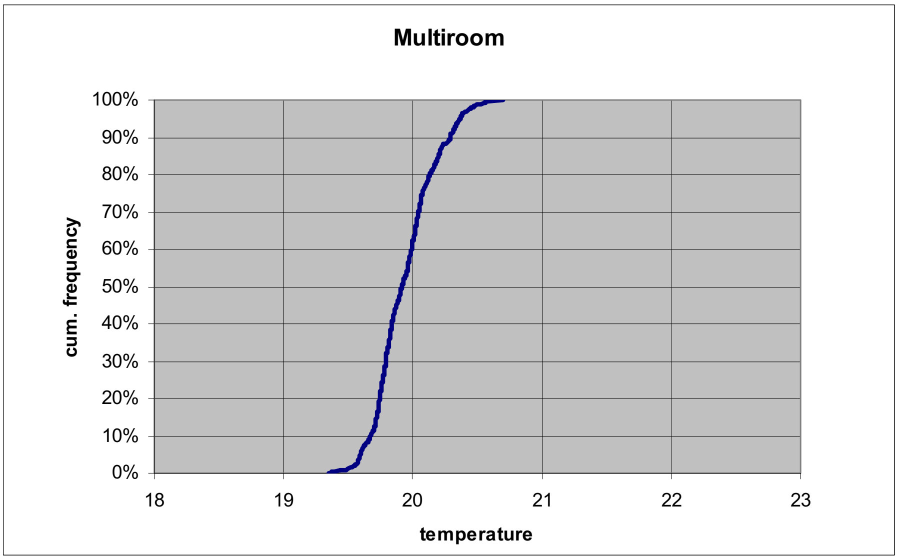


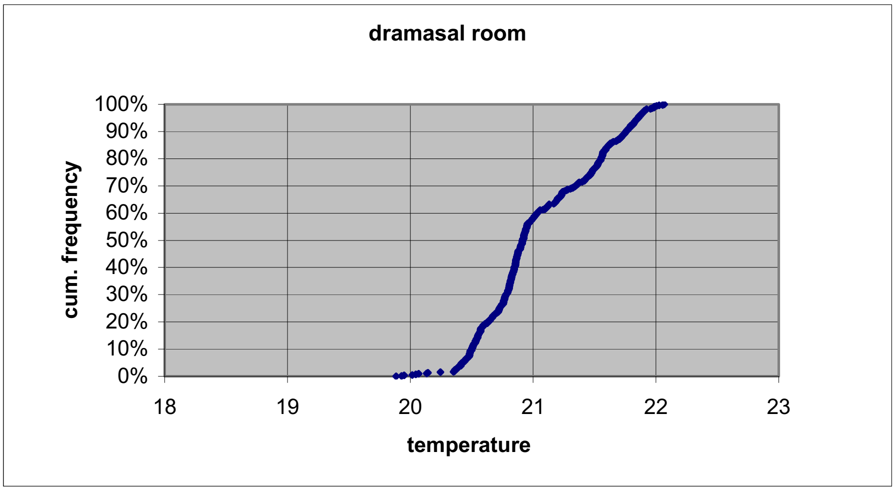
Fig. 5.20 A sketch of the overall heating system design.

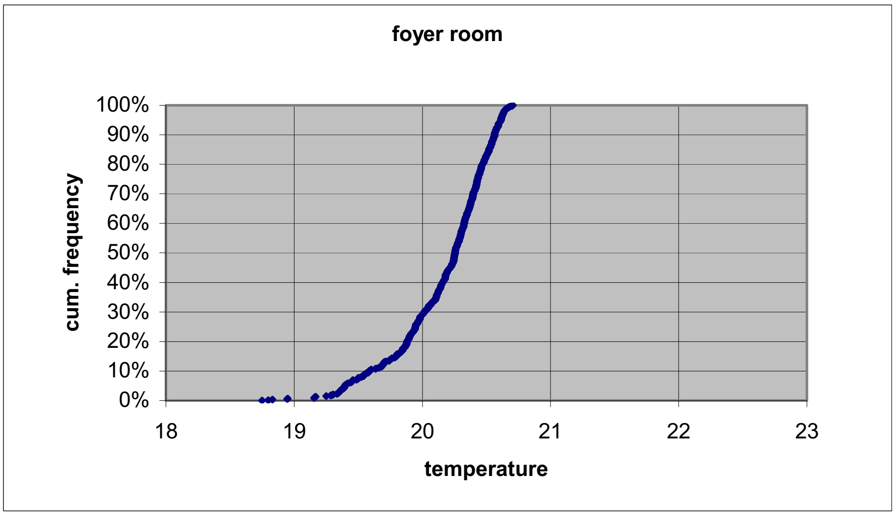
5.8 Thermal comfort

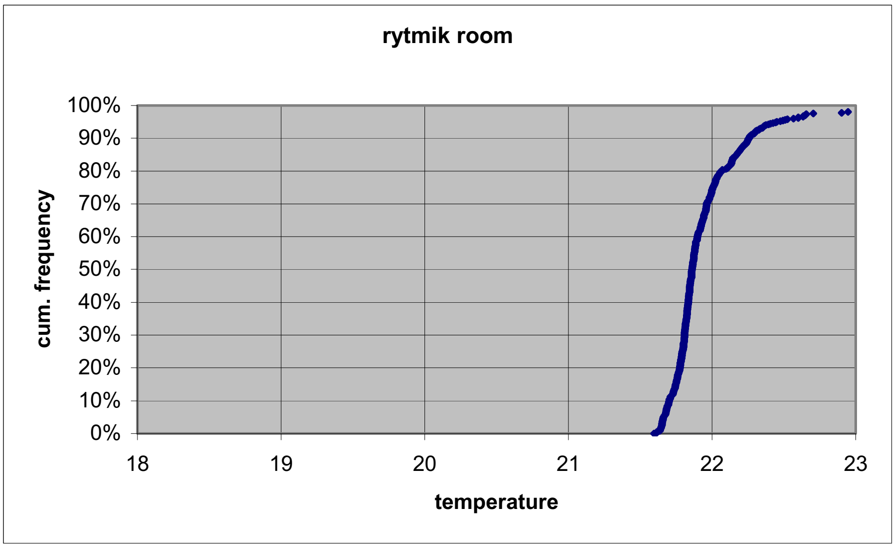
5.8.1 Calculated on the basis of measured data

Cumulative frequency curves of air temperature during working hours in different rooms are presented on the following figures.




dramasal room
cum. frequency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
18
19
20
21
22
23
temperature


foyer room
cum. frequency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
0%
18
19
20
21
22
23
temperature


rytmik room
cum. frequency
100%
90%
80%
70%
60%
50%
40%
30%
20%
10%
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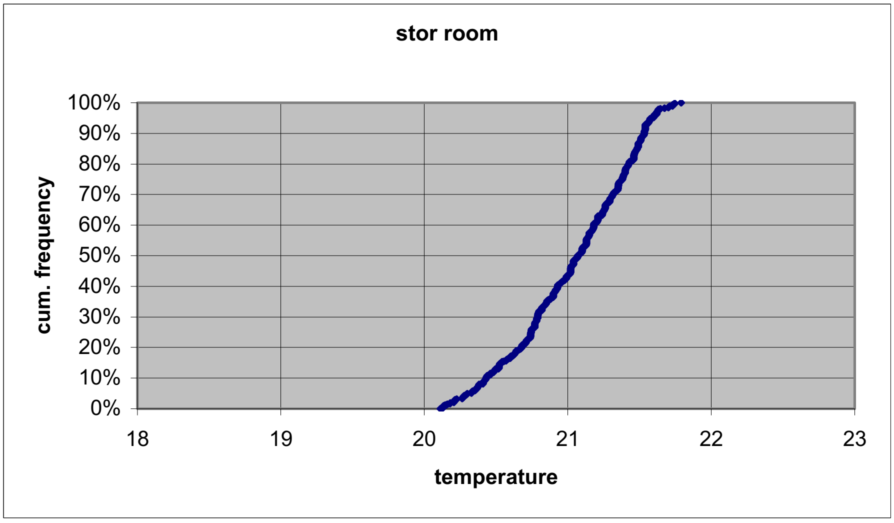
temperature



	Percentage of time with 20<Ta<22 (Winter)	Percentage of time with 19<Ta<22 (Winter)
Drama room	100 %	100 %
Multiple hall	40 %	100 %
Foyer	70 %	100 %
Rhythmic	75 %	75 %
Big hall	100 %	100 %

5.8.2 Reported on basis of users satisfaction enquiry

The temperature in the rooms is generally felt as acceptable. Sometimes it is too high when there are many people present - for example in the drama room. The air quality is also generally very good, with some exceptions in the multiple hall on the first floor. There is generally not felt any draught in the building, neither from the mechanical nor the natural ventilation. The daylight levels are also felt too be good. The acoustics is generally good except that sounds from the gym can be heard to clearly in the drama hall which is clearly unacceptable.

5.8.3 Multi criteria analysis comfort

Variables:
C: Percentage of time with 19<Ta<22 - because in the multiple hall room a lower temperature than 20 is desirable, when the room is used for dancing for example - average: 95.

.

PE: Primary Heating Energy Consumption reduction factor (in comparison to before retrofit situation or to reference building): desired value is 2 ~ >2

Overall Performance function:
$P = F_C \wedge F_{PE}$
$P = W_C*F_C+W_{PE}*F_{PE} = 0.5*0,95 + 0.5*1 = 0.975 \sim 1$

Where:
Weights of Comfort and Primary Energy reduction can be assumed as
$W_C = 0.5$
$W_{PE} = 0.5$

Performance functions of Comfort and P Energy parameters

F_C = C/100 = 0,8

F_{PE} = 1 if $PE \geq 2$, = 1

= 1-(2-PE) if 2> PE >1

= 0 if PE $\leq$ 1

as a conclusion the combined energy and comfort index calculated using the above multicriteria analysis method is very close to 1 - which means that the energy consumption has been reduced to half or better at optimum comfort conditions.

5.9 Summary

5.9.1 Foreseen and Obtained Energy and Water saving

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [MWh/a]	Obtained Total [MWh/a]
Energy saving measures, heating	67.2	79.0	122	143

The monitored heating energy consumption is normalized accordingly to a reference year. The monitored period is from October 2006 to September 2007.

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, electricity	25,2	-22,5?	63000	-41063?
Electricity produced by renewable energy	8,8	9,6	22000	17524

The electricity consumption has been higher than expected - primarily because the cultural centre has been used more for theatrical performances than expected - therefore the used reference numbers were not valid. It is therefore not possible to assess to which extend the electricity saving measures have reduced the electricity consumption. The output from the PV/T and PV are lower for the total values, but higher calculated per m^2. The reason being that the total m^2 in the completed building is lower than originally estimated before the design and construction started.

	Predicted [m^3/m^2 a]	Obtained [m^3/m^2 a]	Predicted [m^3/a]	Obtained [m^3/a]
Water saving measures	0,25	0,93?	625	1697?

Also the water use has been estimated wrongly, this, however, to the higher side. The measured water consumption is much lower than estimated. The main reason is said to be that the school children do not take a shower after having had a gym lesson - or only a few of them does. So, again it is very difficult to assess the effect of the water saving measures.

5.9.2 Overall energy consumption evaluation

	Before retrofit	After Retrofit Foreseen	Saved foreseen	After Retrofit Measured	Saved measured
Primary Energy [kWh/m^{2}a] - heating energy only	132+12.7=145	64.8+12.7=77.5	67.2	79.0	66

5.9.3 Overall Economic evaluation

The result of an overall economic evaluation is presented in the table below.

Total extra costs (Foreseen) [EUR]	Total extra costs (Observed) [EUR]	Saving (Foreseen) [EUR/a]	Saving (Observed) [EUR/a]	PB Foreseen years	PB Observed years
426,749	386,481	30,623	14,851	13,9	26

Energy costs used for calculation (2008):
Thermal : 0,071 Euro/kWh (0,535 DKK/kWh), variable part
Electric: 0,27 Euro/kWh (2.10 DKK/kWh)

The costs of the electricity saving and the water saving measures have been subtracted from the observed cost as the effect of these investments were not possible as explained above. The primary reason for the much higher pay-back time is that the electricity saving measures and the water saving measures had very low pay-back times (~3 years) which means high savings at low investment costs. When they are eliminated from the calculation the payback time rises dramatically.

5.10 Lessons learned

The overall impression from this demonstration project is that estimates for savings based on the use of a building are a lot more difficult to estimate than heating energy savings. In this case the use of the building was completely changed and also the interior of the building was inserted where there had been none before. The estimates of electricity consumption and water consumption were done by the design engineering company based on some key-numbers for "similar" buildings in Denmark. The situation is that there are not many similar buildings and not many of those there are have been monitored in any detail. The lesson to be learned from that is to be careful in planning the monitoring of the energy consumptions of energy uses that are hard to estimate. The heating energy consumption and savings were correctly estimated - they are much less sensitive to the use of the building.
The main impression is that by pushing and trying hard enough you can move “what is possible” quite a bit further than what is first indicated by building designers and contractors. The examples of this experience are:
The finding of the architect that the minimal construction of the roof was already strengthened because of the crane, so it could actually carry the weight of the additional insulation

The competition between the window manufactures made it possible to come up with quite low U-values for the whole window even considering the rather small individual glazing areas.

As always the first reaction from the contractors is that "this is too expensive". In the actual situation it was the BEMS system. But by negotiations it finally got through the process.

Many people has visited Prøvehallen and has with great interest learned about the energy saving measures and the renewable energy systems. The visitors have been met with this information about the BRITA project on a monitor inside the reception hall as shown on the photo below.

The BRITA in PuBs project is an EU-supported demonstration project that aims to increase the market penetration of innovative and cost-effective retrofit solutions to improve energy efficiency and implement renewable energy in public buildings all over Europe.

All demonstration projects have the goal to reduce the primary energy consumption at least by factor 2 and at the same time increasing user comfort considerably

When the visitors are guided by someone from Prøvehallen or someone else with a knowledge about the BEMS system information on the operation of the building can also be shown on this screen, for example yearly energy consumption or temperature graphs from a particular room. See the example below.

5.11 Appendices

1: SE123W-PVT-Thermal-module-data

PV Thermal	RAcell Solar A/S	12/07/05

PV/Thermal module w. Glass front/Copper rear
Valby Ny Skole Heat-pump / PVT Project

Characteristics of a PV module

PV module : **RAcell Ltd, SE123W-PV/T, @12V**

STC power (manufacturer)	**PNom**	**123**	**Wc**	**Technology**		**Si-poly**	
Module size (W x L)	.	0.665 x 1.465	m²	Rough module area	Amodule	0.97	m²
Number of cells		1 x 36		Sensitive (cells) area	Acells	0.88	m²

Specifications for the model (manufacturer or measurement data)

Temperature reference cond.	Tref	25	°C	Irradiation reference	Gref	1000	W/m²
Open circuit voltage	Voc	21.9	V	Short circuit current	Isc	7.60	A
Maximum power point voltage	Vmpp	17.6	V	Max. power point current	Impp	7.00	A
=> maximum power	Pmpp	123.2	W	Isc temperature coefficient	mu ISC	2.3	mA/°C

One-diode model parameters

Shunt resistance	Rsh	180	ohm	Saturation current at 20°C	Io	92	nA
Series resistance	Rs	0.15	ohm	Voc temp. coefficient	muVoc	-73	mV/°C
				Diode quality factor	Gamma	1.30	

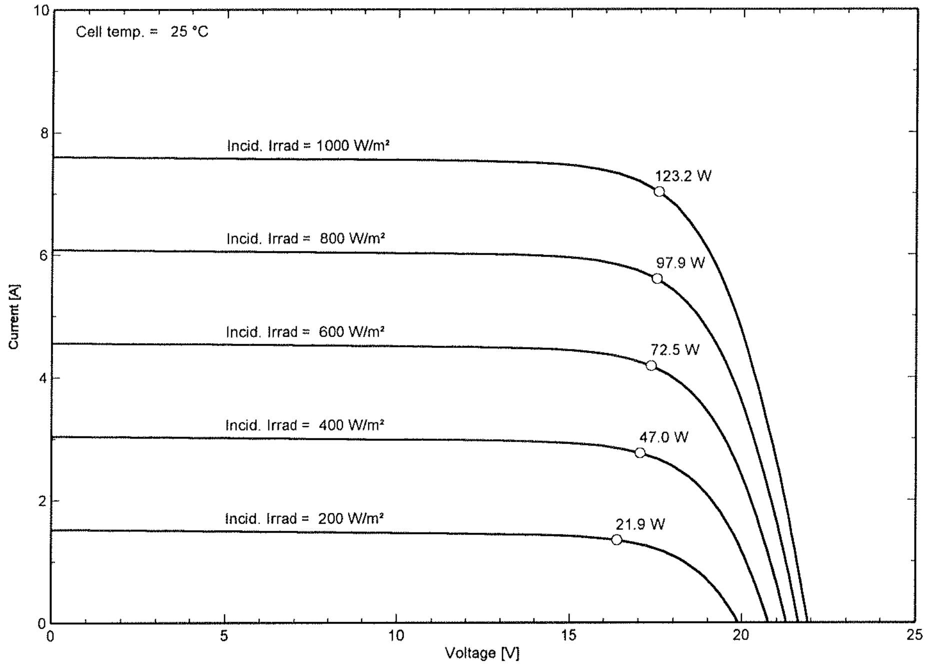
Reverse bias parameters, for use in behaviour of PV arrays under partial shadings or mismatch

Reverse characteristics (darkness)	Brev	3.20	mA/V²	(quadratic factor, per cell)			
Number of by-pass diodes per module		2		By-pass diode reverse voltage	Vrev	-0.7	V

Model results for standard conditions (STC: T=25°C, G=1000 W/m², AM=1.5)

Maximum power point voltage	Vmpp	17.6	V	Maximum power point current	Impp	7.01	A
Maximum power	Pmpp	123.2	Wc	Power temper. coefficient	muPmpp	-0.44	%/°C
Efficiency (/ module area)	Eff_mod	12.6	%	Fill factor	FF	0.740	
Efficiency (/ cells area)	Eff_cells	14.1	%				

PV module : RAcell Ltd, SE123W, @12V



PV Thermal	RAcell Solar A/S	12/07/2005

Sct. Thomas House - DK 1820 Frb. Copenhagen - Denmark

Characteristics of a PV module

PVT module : **RAcell Ltd, SE123W, @12V**

STC power (manufacturer)	**PNom**	**123**	**Wc**	**Technology**		**Si-poly**	
Module size (W x L)		0.665 x 1.465	m^2	Rough module area	Amodule	0.97	m^2
Number of cells		1 x 36		Sensitive (cells) area	Acells	0.88	m^2

Specifications for the model (manufacturer or measurement data)

Temperature reference cond.	Tref	25	°C	Irradiation reference	Gref	1000	W/m^2
Open circuit voltage	Voc	21.9	V	Short circuit current	Isc	7.60	A
Maximum power point voltage	Vmpp	17.6	V	Max. power point current	Impp	7.00	A
=> maximum power	Pmpp	123.2	W	Isc temperature coefficient	mu ISC	2.3	mA/°C

One-diode model parameters

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Series resistance	Rs	0.15	ohm	Voc temp. coefficient	muVoc	-73	mV/°C
				Diode quality factor	Gamma	1.30	

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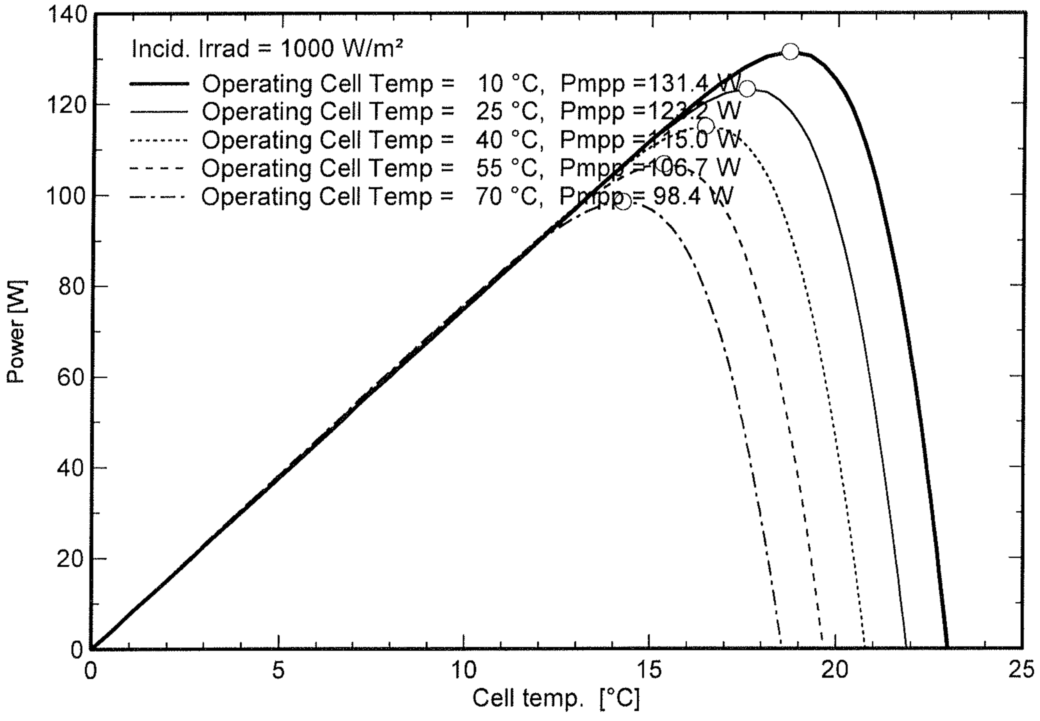
Maximum power point voltage	Vmpp	17.6	V	Maximum power point current	Impp	7.01	A
Maximum power	Pmpp	123.2	Wc	Power temper. coefficient	muPmpp	-0.44	%/°C
Efficiency (/ module area)	Eff_mod	12.6	%	Fill factor	FF	0.740	
Efficiency (/ cells area)	Eff_cells	14.1	%				

PV module : RAcell Ltd, SE123W, @12V



PV Thermal	RAcell Solar A/S	12/07/2005

Valby Ny Skole Heat-pump / PVT Project
PV/Thermal module w. Glass front/Copper rear

Characteristics of a PV module

PV module : **RAcell Ltd, SE123W-PV/T, @12V**

STC power (manufacturer)	**PNom**	**123**	**Wc**	**Technology**		**Si-poly**	
Module size (W x L)	.	0.665 x 1.465	m^2	Rough module area	Amodule	0.97	m^2
Number of cells		1 x 36		Sensitive (cells) area	Acells	0.88	m^2

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=> maximum power	Pmpp	123.2	W	Isc temperature coefficient	mu ISC	2.3	mA/°C

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Reverse bias parameters, for use in behaviour of PV arrays under partial shadings or mismatch

Reverse characteristics (darkness)	Brev	3.20	mA/V^2	(quadratic factor, per cell)			
Number of by-pass diodes per module		2		By-pass diode reverse voltage	Vrev	-0.7	V

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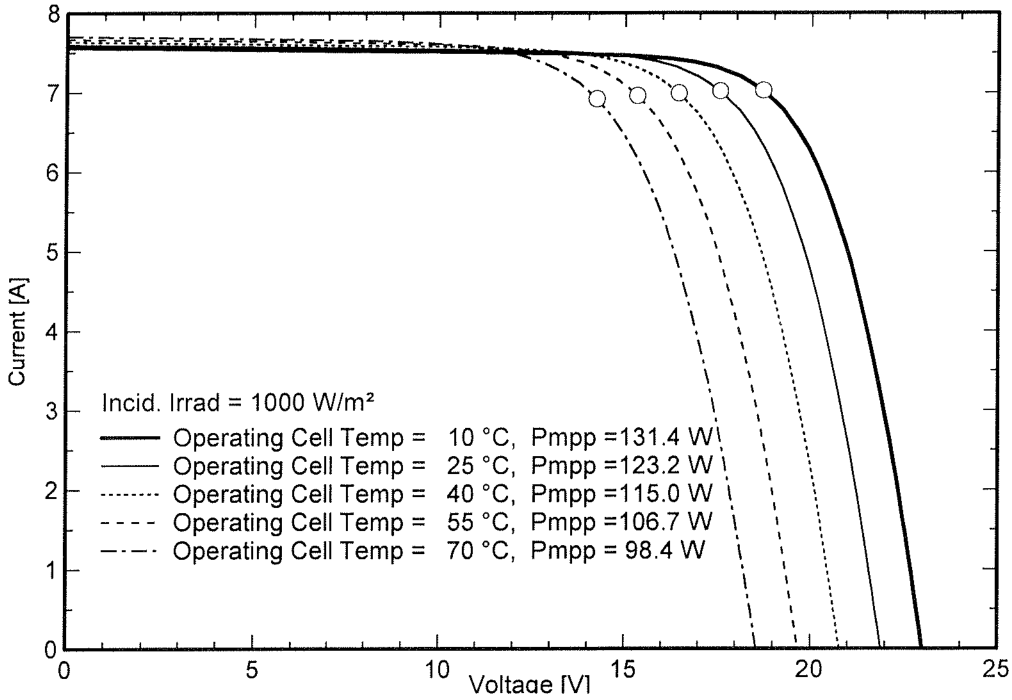
Efficiency (/ module area)	Eff_mod	12.6	%	Fill factor	FF	0.740	
Efficiency (/ cells area)	Eff_cells	14.1	%				

PV module : RAcell Ltd, SE123W, @12V



6. The Brewery – students' social and cultural centre

Authors: Pavel Charvat, Miroslav Jicha

6.1. General data

6.1.1. General information

Year of construction: 1770s
Year of renovation (start): 2004
Number of storey: 2 and 4

Heated volume, 10 880 m^3
Cubic contents 8 420 m^3
Heated floor area: 2 660 m^2 (2 300 m^2 before the retrofit)
Living area: 584 m^2 (guest rooms)
Window/glass area: 145.5 m^2

6.1.2. Site

The "Brewery" is located in the north-west part of the city of Brno. The city of Brno is the largest city in the province of Moravia (the south-east part of the Czech Republic). The population of Brno is around 370 000 people. The city of Brno lies in the basin of the Svratka and Svitava rivers, surrounded by wooded hills on three sides and opened to the South Moravia lowlands on the south. The altitude ranges from 190 to 425 meters. The coordinates of Brno are 49.2 N, 16.4 E.

Fig. 1 Location of the city of Brno

The "Brewery" is located in one of the old parts of the city. There are only low-rise buildings in the vicinity of the "Brewery", many of which are more than a century old. The altitude of the site is 227 m. The winter design temperature is -12 °C. The summer design conditions are: temperature 32 °C and enthalpy 62 kJ/kg. The long-term climatological normals (outdoor temperature and solar radiation incident on horizontal surface) for the period of 1961–1990 are shown in Table 1. The mean air temperature has deviated from the above mentioned normals in last couple of years, as can be seen in Table 2. The average sunshine duration in that period 1961–1990 was 1680 hours/year and the average precipitation 494 mm/year.

Table 1 The long-term climatological normals for the city of Brno (www.chmi.cz)

	Month												Year
	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	
Outdoor temp. [°C]	-2.5	-0.3	3.8	9.0	13.9	17.0	18.5	18.1	14.3	9.1	3.5	-0.6	8.7
Solar radiation [kWh/m^2]	25	44	82	116	158	159	172	144	96	65	28	20	1107

Table 2 The mean air temperature in Brno in the last decade.

	Year									
	1998	1999	2000	2001	2002	2003	2004	2005	2006	2007
Outdoor temp. [°C]	9.6	9.9	10.8	9.2	9.2	9.9	9.4	8.9	9.1	10.6

6.1.3. Building type

The Brewery is an old industrial-type building in a historical area that was reconstructed for the use of the Faculty of Information Technologies of the Brno University of Technology (Fig. 2). The building was originally used as a brewery, but in the recent past it served as a warehouse. The retrofitting of the Brewery involved a complete change of the user profile. The former brewery has been transformed into a modern social and culture center for students and academics. This had a big impact on the design phase, because all building services had to be designed from scratch.

Fig. 2 Arial view of vicinity of the Brewery

6.2. Before retrofit

6.2.1. Building construction

The oldest part of the Brewery was built in 1770s. The building has been extended and rebuilt several times during more than 200 years of its history. The Brewery currently consists of two buildings. The four-storey building (designated R building) contains some original building structures dating back to the eighteen century. A stone with a date of 1769 was discovered during the retrofit in one of the columns supporting the vaulted ceilings on the ground floor. The two-storey building (designated P building) was build later, but it also has a historical value, especially the cast iron columns supporting the ceilings. Another two-storey building adjacent to the Brewery at the south was torn down just before the retrofit. The elevations of the Brewery before retrofit are shown in Fig. 3. The floor plans of the R building and P building can be seen in Fig. 4 and Fig. 5. Fig. 6 shows four sections the building before retrofit.

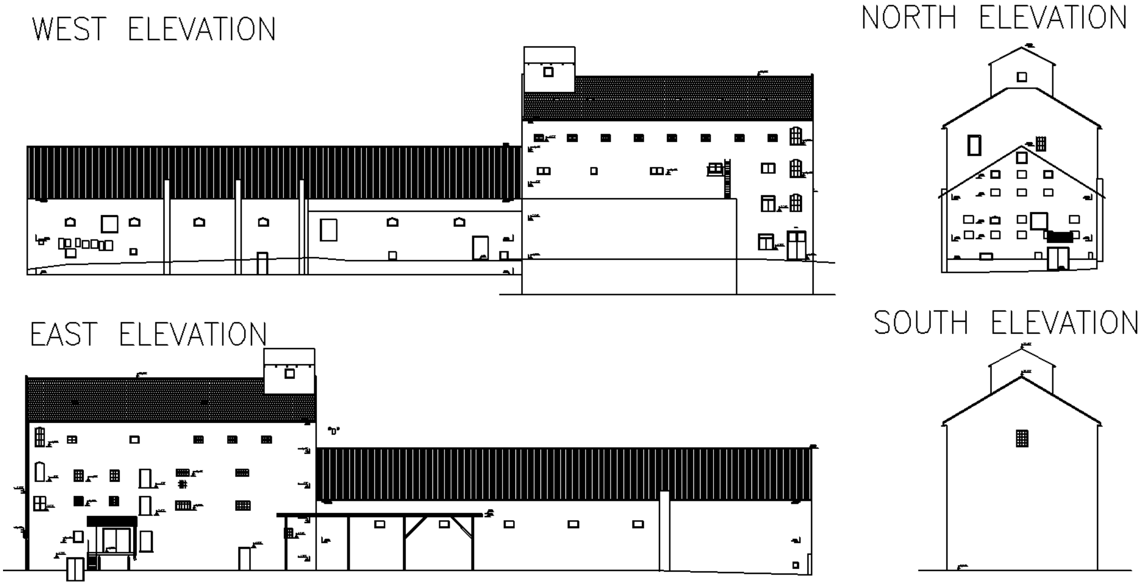


Fig. 3 Elevations – situation before retrofitting

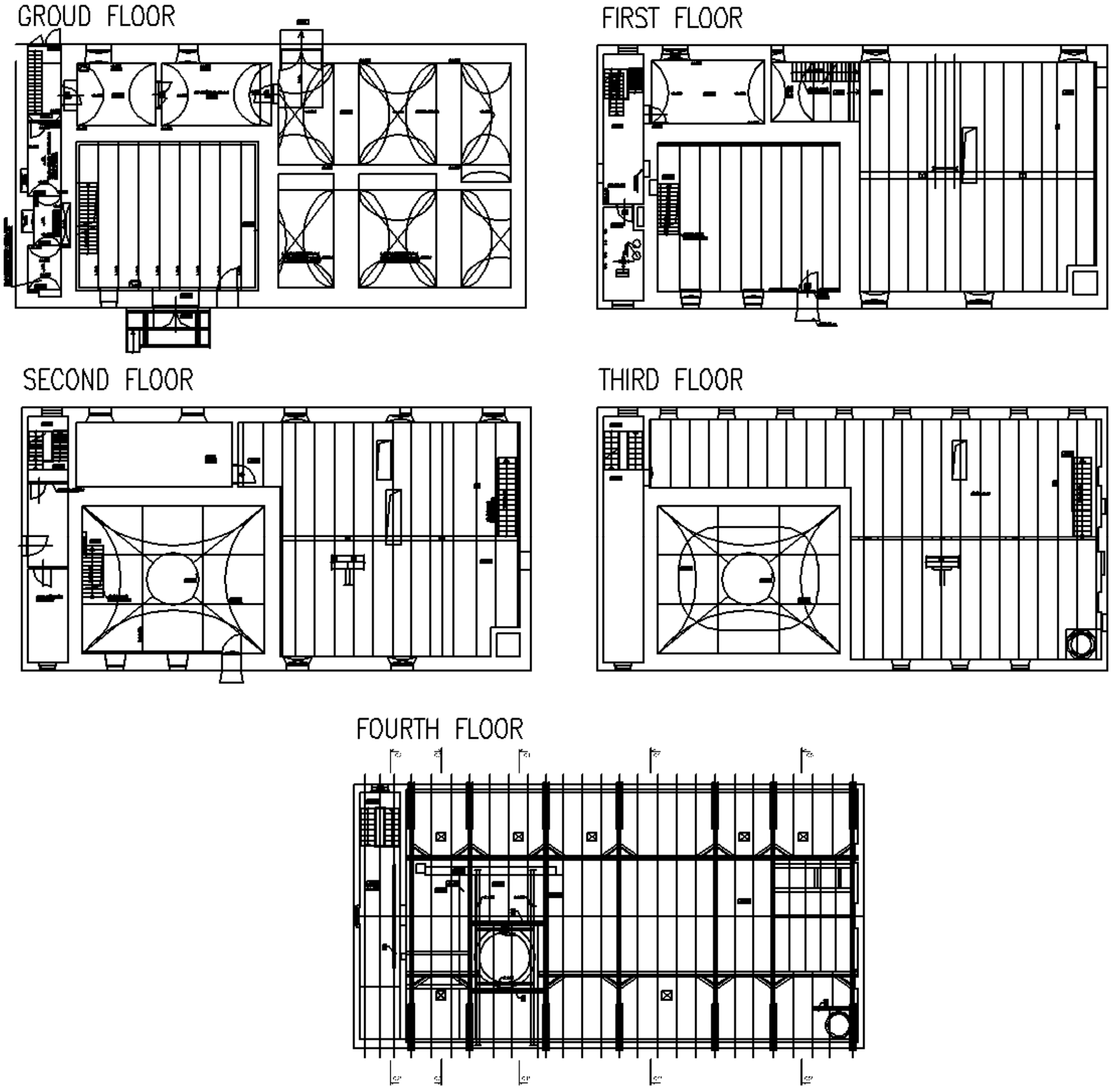


Fig. 4 Floor plans of the R building (before retrofit)

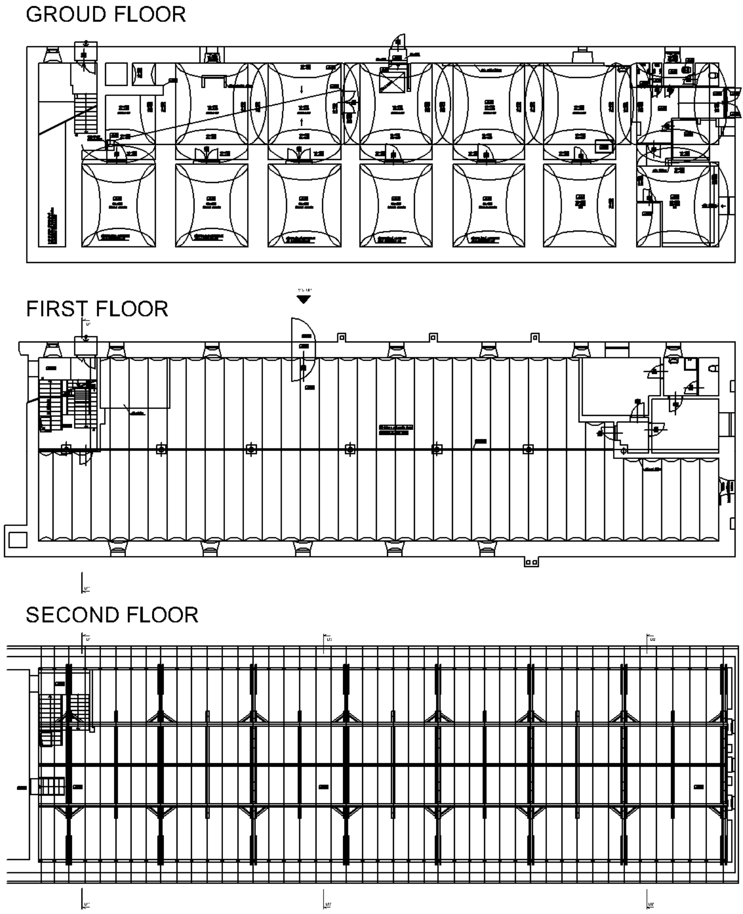


Fig. 5 Floor plans of the P building (before retrofit)

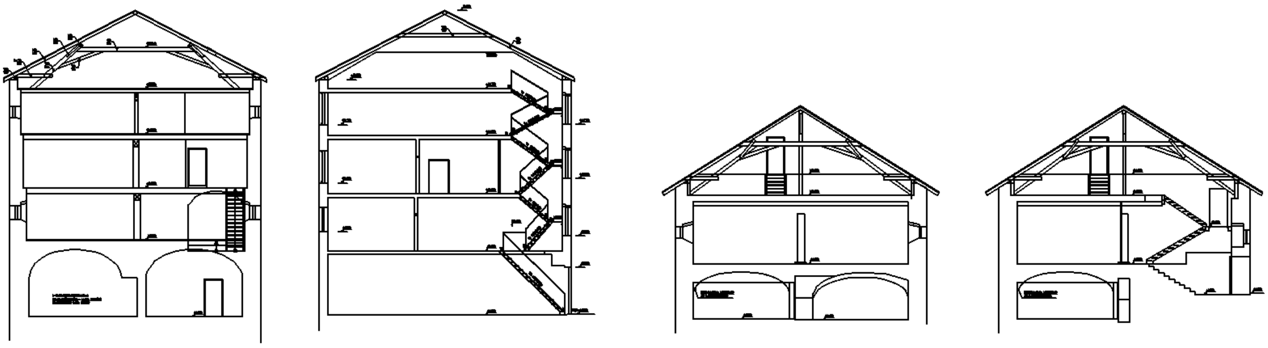


Fig. 6 Sections – situation before retrofit

The walls of the buildings are made of burnt bricks. The external walls are 1 meter thick. The foundations of the building are quite old and the foundation pressure exceeded the bearing capacity of the foundation soil. The reinforcement of the foundations was the first step that had to be done when the retrofit started. The vertical load-bearing constructions and the brick vaults also needed some fixing and some vaults had to be built again. This, of course, required more than a bit of craftsmanship of the construction workers.

The timberwork of the roofs was in a relatively good shape, but some beams had to be replaced.

The ceilings in the Brewery are of various constructions. There are brick vaults on the ground floor (Fig. 7a) and the upper floors have either beam ceilings (Fig. 7b) or brick ceilings supported by a riveted girder on cast-iron columns (Fig. 7c).

a) b) c)

Fig. 7 Ceiling types in the Brewery

6.2.2. Existing heating, ventilation, cooling, lighting systems

The building served as a warehouse for many years and there was no usable heating system in the building before retrofitting. The coal fired heaters (stoves) were used for heating in some of the rooms in the past, but these were not in operation since the building became a warehouse.

The building was naturally ventilated, but there were no purpose provided openings for the air supply, except of the windows. The old buildings with solid fuel fired heaters (stoves) could not be very airtight because the make-up air for combustion was needed and the air entered the buildings by infiltration. There was no cooling system in the Brewery, but there were spacey cellars for beer storage close to the building. The ice used to be used in the cellars as a cooling medium that kept beer cool. The cellars were flooded with water and an idea was explore to use the flooded cellars as a heat reservoir for reversible heat pumps providing heating in winter and cooling in summer.

6.2.3. Energy and water use

Since the building had not been used for many years in recent past, no measured data about the energy consumption was available. An estimation of the energy consumption for the brewery profile was made. The first estimate was based on the benchmark data (for industrial type buildings) and it did not seem to be relevant as a baseline for the assessment of energy savings. Another estimate was produced later on when more input data was available. This estimate was done for the social centre profile and involved both benchmark data and calculations. The results of this estimate are shown in Table 3.

Table 3 The estimated energy and water consumption before retrofit

	Pre-retrofitting estimate for the students' centre user profile	**Total for the whole building**
Space heating	235 kWh/m^2 a	541 MWh/a
Mechanical ventilation	52 kWh/m^2 a	119 MWh/a
Electricity	71 kWh/m^{2}a	164 MWh/a
Water	6.6 m^3/m^{2}a	15 100 m^3/a

6.2.4. User satisfaction before retrofit

The retrofit of the Brewery involved complete change of the user profile. Brewery, that used to be an industrial type building, was converted into a multi-purpose social and culture centre. No data on user satisfaction from the time before retrofit have been available.

6.3. Energy saving concept

Both passive and active measures have been present in the energy saving concept. Passive measures, like additional insulation or replacement of windows, represent more or less a “traditional” approach to a retrofit of a building in the Czech Republic. Active measures, like the installation of a Building Energy Management System or integration of photovoltaic, are innovative and have not been used in a mass scale yet.

6.3.1. Building construction

As mentioned earlier, the Brewery has 1 meter thick brick walls. This huge thermal mass dampens the impact of the fluctuations of outdoor air temperature on the temperature inside. One of the ideas at the beginning of the project was to employ the heavy mass of the walls as heat storage mass. The double skin facade was supposed to be placed on the south wall of the building. The facade would contain semi-transparent PV modules and the air gap in the double facade would work as transparent insulation in winter and a solar chimney in summer. The solar chimney would be employed for passive cooling and even night cooling, because solar heat absorbed by the brick wall during day could be released at night and thus support the chimney effect. Finally, the university decided to reserve the place in front of the facade for further development of the campus. It was very likely that another building would be build close to the south facade in future. The double-skin facade would be shaded by this building most of the time. All means of solar energy utilization on the south facade had been abandoned. The part of the east wall was also supposed to be covered with a double skin facade, but this was more or less for the aesthetic reasons in connection with double skin on the south wall. No double-skin facades were installed at the Brewery what helped the building to preserve its appearance of an early-industrial-age building. This impression could even get stronger if the building had naked red brick walls on the outside. However, cleaning and repairing of the red bricks would be expensive and additional thermal insulation on the outside could not be used.

New windows with the glazing U-value = 1.1 $W.m^{-2}K^{-1}$ replaced the old single-pane windows. Some of the external walls got additional thermal insulation of 100 mm of polystyrene on the outside. The roof of the P building was insulated with 160 mm of mineral wool when the attic was converted into habitable space with 21 guest rooms. The floors adjacent to the ground got additional insulation of 60 mm of polystyrene, and the ceilings under the loft in the R building were thermally insulated with 160 mm of mineral wool. The U-values of the building constructions before and after retrofit are listed in Table 4.

Table 4 U-values of the building constructions

	U-value [$W\ m^{-2}\ K^{-1}$]	
	before retrofit	after retrofit
windows	5.20	1.3 (overall) 1.1 (glazing)
external walls (not to be insulated)	0.7	0.70
external walls (to be insulated)	1.8	0.36
ceilings (under the unheated lofts)	1.3	0.22
roofs (attic converted into habitable space)	5.0	0.25
floors adjacent to ground	3.5	0.60

6.3.2. Heating

The building did not have a heating system before the retrofit. Therefore, the design of the heating system started from scratch. The Czech Republic has quite a developed system of district heating in cities and bigger towns. The cost of heat from the district heating, however, increased so much in the last decade that the district heating lost its competitiveness. The main reason is the condition of the infrastructure (distribution system) that has enormous thermal losses and with the decreasing demand leads to high prices of delivered heat. The customers are not willing to pay for the heat that gets lost in the distribution network new buildings usually have their own heating plants.

An idea was explore to use the flooded cellars as a heat reservoir for reversible heat pumps providing heating in winter and cooling in summer. The pumping tests revealed that water inflow into the cellars would not probably be sufficient to provide enough heat for heating. Moreover, air handling units of air conditioning system would have to be fitted with bigger heat exchangers since water temperature at the outlet of a heat pump is usually lower than 60°C.

Another considered option was the CHP (combined heat and power). The Brno University of Technology already has two installations of the CHP units, one at the Faculty of Mechanical Engineering and the other at the dormitories. The CHP unit at the Faculty of Mechanical Engineering only operates between 8 A.M. and 4 P.M. on workdays when there is a demand for domestic hot water. The CHP units at the dormitories, where 3000 students are staying, and where some cafeterias and restaurants are opened till late hours in the evening, have much better conditions for operation, because the hot water is demanded throughout the day. The demand for hot water in case of the Brewery is quite small in summer, and so the CHP would not to be a good solution.

A heating plant fitted with two condensing gas boilers was chosen as the most suitable option. The problem with the high water temperature for the air handling units and domestic hot water (DHW) remained, but it was solved by introduction of two loop system. Low temperature loop used for space heating runs trough the flue gas heat exchanger of the boilers and thus allows them to operate in condensing mode. The individual control of heating with temperature sensors in most of the rooms was introduced to save energy by a possibility to set a different heating profile for each room. Moreover, windows in guest rooms are fitted with sensors and heating and cooling in a room shuts down when a window is opened. The VRV air-conditioning system which is installed in the guest rooms can help heat up a room from energy saving setpoint temperature to comfort level setpoint temperature. An air-to-water heat pump for DHW heating is installed in the club. The heat pump is used in summer when the main heating plant with condensing boilers does not operate. Cool air from the heat pump is supplied to the room and thus provides little bit of cooling.

6.3.3. Ventilation

The Brewery as a students' social and cultural centre involves several facilities with different profiles of operation and therefore the different requirements on ventilation. The cafeterias and kitchens are supposed to operate only on weekdays and only for about six hours a day. The ventilation demand, however, is quite high during the operation hours. A mechanical ventilation system with heat recovery was chosen for cafeterias and kitchens, because it fulfils requirements best. Very similar situation is in the club, auditorium and two multi-purpose rooms where mechanical ventilation is used as well.

The accommodation services are supposed to be in operation all year round and the occupancy of rooms, and therefore the ventilation demand, varies significantly in time. A demand controlled ventilation system was designed for the guest rooms. The hybrid ventilation system is controlled by the Building Management System with regard to the air quality in rooms.

6.3.4. Cooling

The cafeterias and kitchens need cooling in summer because of the high internal heat gains. The air-handling unit are fitted with cooling coils in order to provide cooling for these areas. Chilled water for the cooling coils is supplied from the central cooling plant, which is located at another building in the campus. The central cooling plant has the cooling capacity of 600 kW and provides chilled water for the new built premises (lecture halls, computer labs, offices), where the most of the cooling demand is concentrated. The lecture halls, laboratories, and classrooms in the new premises as well as the cafeterias and kitchens in the Brewery only operate during academic year. The main cooling loop supplying cold water to these parts is supposed to be shut down for the summer break, because there is no demand for cooling. A smaller cooling loop provides cooling water for server rooms that operate all year round. Some of the guest rooms are located in the attic directly beneath the roof. Space cooling is needed to maintain acceptable thermal comfort in the guest rooms in summer. Since the small cooling loop operating in summer does not have sufficient capacity to provide cooling for guest rooms a Variable Refrigerant Volume (VRV) air-conditioning system was installed in the guest rooms. The consumption of electricity of the VRV air-conditioning system will be compensated by the PV modules installed on the roof.

6.3.5. Lighting systems

The Brewery has relatively small window area. The ratio between the total area of windows and the total floor area is around 5.5 %. Except of the guest rooms the artificial lighting has to be on almost all the time when a space is used. The situation is better in the guest rooms where dormers provide sufficient lighting during the day. The use of the light pipe skylights was considered in the corridors with no windows. This idea had to be abandoned, because there was not enough space for the light pipes. The sensor controlled lighting was installed in the corridors instead.

6.3.6. BEMS

The Building Energy Management System (BEMS) in the Brewery is a part of the Building Management System (BMS) of the campus of the Faculty of Information Technologies. Beside the control of heating, lighting, ventilation and air-conditioning the BMS involves the access and security system, fire alarm, closed circuit television (CCTV), etc. It is not really possible to separate BEMS from the BMS because some information, like presence of people obtained from the access system (BMS), is used for the control of heating and cooling (BEMS).

6.3.7. Predicted energy savings

Predicted energy savings are shown in Table 5. Each energy-saving measure was evaluated separately. The biggest energy-saving potential is expected from the condensing boilers. The condensing boilers are not yet as widely used in the Czech Republic as in the “old” EU member states. This is especially true for the boilers with thermal outputs over 50 kW. There is a number of reasons for that. The condensing boilers are more expensive than the regular ones. The heating systems have to be designed for lower water temperatures and that also increases costs. Low water temperature can be especially painful in connection with air-handling units were lower water temperatures mean bigger heat exchangers resulting in higher pressure drops. Another problem is neutralization of condensate that is required for condensing boilers above certain output.

Table 5 Predicted energy savings

Energy saving measures	[kWh/m^{2}a]	Total [kWh/a]
Heating energy		
Insulation of roofs and facades	24.3	56 000
Low-e windows	32.5	74 750
Condensing boilers	45.3	104 100
Individual control of heating	9.3	21 400
Waste heat recovery (mech. ventilation)	29.9	68 850
CO_2 controlled hybrid ventilation	8.6	19 900
BEMS (heating saving)	15.4	35 500
Total heating energy savings	**165.4**	**380 500**
Electricity		
Photovoltaic cells	14.3	33 000
Daylighting	2.4	5 600
Heat pump for DHW	1,7	3 900
BEMS (electrical saving)	3.9	9 000
Total electrical energy savings	**22.4**	**51 500**

6.3.8. Predicted costs and payback

The predicted costs and payback times are in Table 6. The predicted payback time, calculated from the prices of energy stated below, is 20.2 years. At this moment we can say that the actual payback time will be shorter since the prices of energy increased by almost 10 percent in January 2008.

Table 6 Predicted costs and payback times

Energy saving measure/investment	Area [m²]	Total costs [EUR]	Saving [EUR/a]	Pay-back periods [a]
Insulation of roofs and facades	1360	100 000	3 472	28.8
Low-e windows	154	72 000	4635	15.5
Condensing boilers		28 000	6 454	4.3
Individual control of heating		47 000	1 327	35.4
Waste heat recovery (mech. ventilation)		15 500	4 269	3.63
demand controlled hybrid ventilation		90 000	1 234	72.9
BEMS (heating saving)		35 000	2 201	15.9
Photovoltaic modules	140	110 000	6 160	17.9
Daylighting system		4 200	616	6.8
Heat pump for DHW		2 500	429	5.8

BEMS (electrical saving)		15 000	990	15.2
Total		**519 200**	**31 786**	**16.3**

Energy costs used for the payback calculation:
Thermal: 0.062 Euro/kWh
Electric: 0.11 Euro/kWh (0.44 for the PV system)

6.4. Life Cycle Assessment

To carry out an energy retrofit of a building means to use certain amount of energy in order to apply energy saving measures. Also the products and materials used in the retrofit have a certain amount of embodied energy. This energy would not be spent if the energy retrofit was not done. For the complete analysis of the energy payback time, it is important to include the embodied energy of the materials and products used in the retrofit and also energy used for construction work. The results of such an analysis for the retrofit of the Brewery can be found in Table 7. Only materials, products and energy directly connected with the aplication of the BRITA in PuBs energy saving measures were considered in the LCA analysis.

Table 7 The results of life cycle analysis

Primary energy saving and emissions			
Primary energy save (E_{year})	14 814 628.0		[kWh]
Global Emission saving (EM_{S-i})	3 107.0		[$ton_{CO2\ eq.}$]

Summary of materials employed and main components			
Component			
Mineral wool	1.2		[ton]
Brick	2.0		[ton]
Concrete	2.5		[m^3]
Cast-iron	1.2		[ton]
Timber	3.5		[ton]
High efficient windows	112.0		[m^2]
Monocrystalline PV plant	113.0		[m^2]
Condensing boilers	700.0		[kW]
Ventilation & cooling systems (overall mass)	1 286.0		[kg]
Pipes and radiators (steel)	4.8		[ton]
Pipes (copper)	0.8		[ton]
Glass wool	279.0		[kg]
Polystyrene	126.0		[kg]
Polyolefin	77.0		[kg]

Energy and Environmental Indexes			
Global Energy Requirements (GER)	399 550.0		[kWh]
Global Warming Potential (GWP)	69.3		[ton $CO_{2\text{-Eq.}}$]
Nutrification Potential (NP)	53.0		[kg PO_4]
Acidification Potential (AP)	556.3		[kg SO_2]
Ozone Depletion Potential (ODP)	0.03		[kg CFC_{11}]
Photochemical Ozone Creation Potential (POCP)	62.8		[kg C_2H_4]

Synthesis Indexes			
Energy Payback Time ($E_{\text{-PT}}$)	0.6		[year]
Emission Payback Time ($EM_{\text{-PT}}$)	0.5		[year]
Energy Return Ratio (E_R)	37.1		

6.5. Construction phase description

Construction phase in the retrofits of old buildings is the phase when many problems pop up. Even if a thorough survey of the technical state of a building was done prior the design phase many defects in the building constructions can only be revealed when the construction phase begins. These defects have to be fixed what means extra costs and it can possible have some implications for the solutions suggested in the design phase.

6.5.1. Building construction

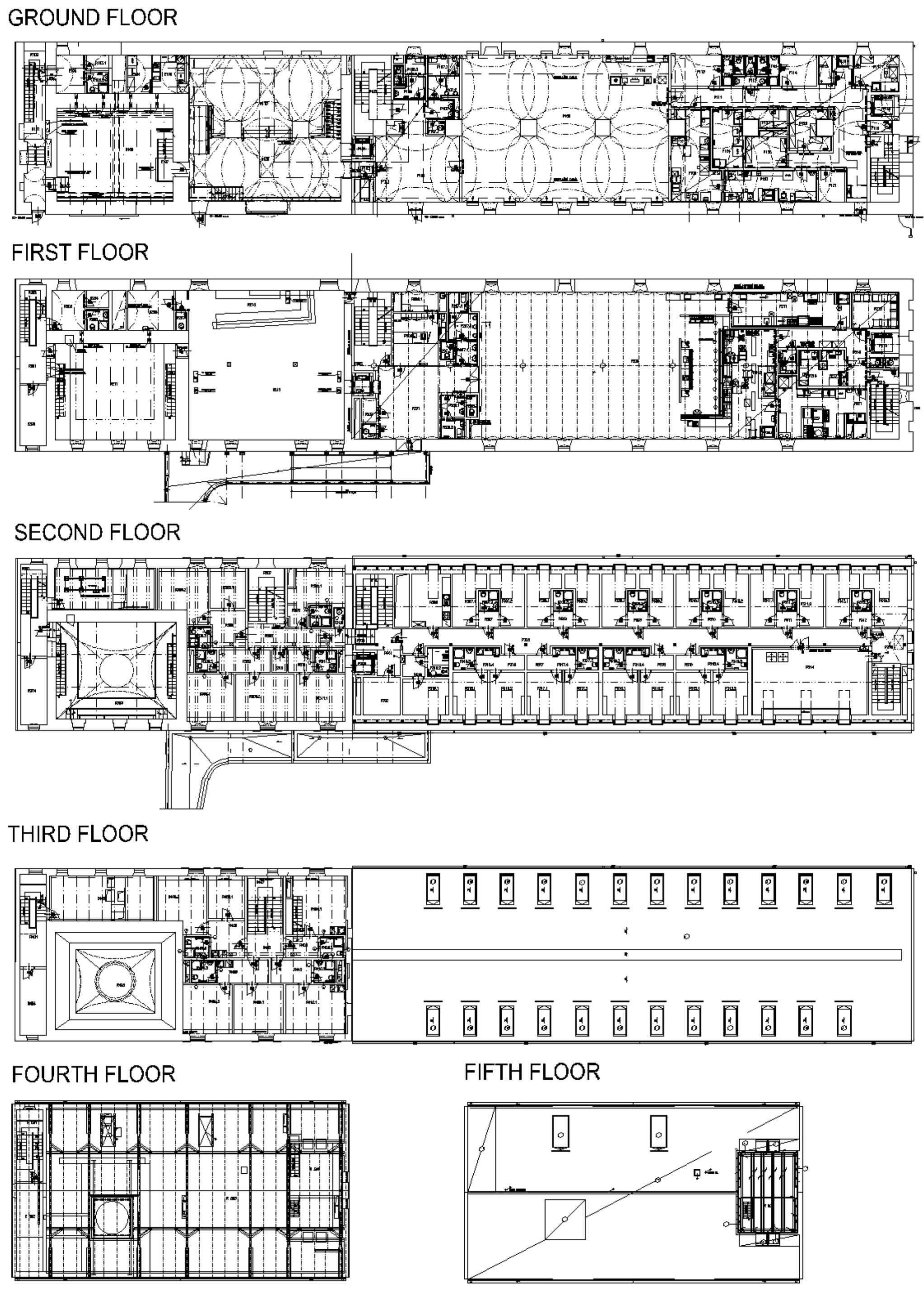
The main problem in case of the building construction was overloading of the foundation soil. The Brewery has very shallow foundations and the foundation pressure was too high. This caused cracking of the load bearing walls. A new building with an underground parking lot was to be built just a few meters from the Brewery (Fig. 8). The big excavation for the parking lot threatened to affect the stability of the foundations. The foundation soil could slide down towards the hole or its bearing capacity could be affected by variation in underground water level (underground water flow into a hole). The sensors were installed in the walls in order to monitor the behaviour of the cracks during the digging. Some reinforcement of the foundation has also been done and this way the problem has been overcome.

Fig. 8 The underground parking lot

The usable floor area of the Brewery was increased during retrofit as the attic of the P building was converted into habitable space (guest rooms). The progress of this work, with the first dormer erected is in Fig. 9.

Fig. 9 Conversion of the attic into habitable space

The floor plans of the complete building after retrofit are in Fig. 10. There is a cafeteria and two multipurpose rooms on the ground floor. Another cafeteria, a student club and an auditorium are located on the first floor. The accommodation services (guest rooms) are on the second and the third floor. A tunnel at the level of the first floor connects the Brewery with the adjacent building. The sections of the building can be seen in Fig. 11.



GROUND FLOOR

FIRST FLOOR

SECOND FLOOR

THIRD FLOOR

FOURTH FLOOR

FIFTH FLOOR

Fig. 10 Floor plans – situation after retrofit

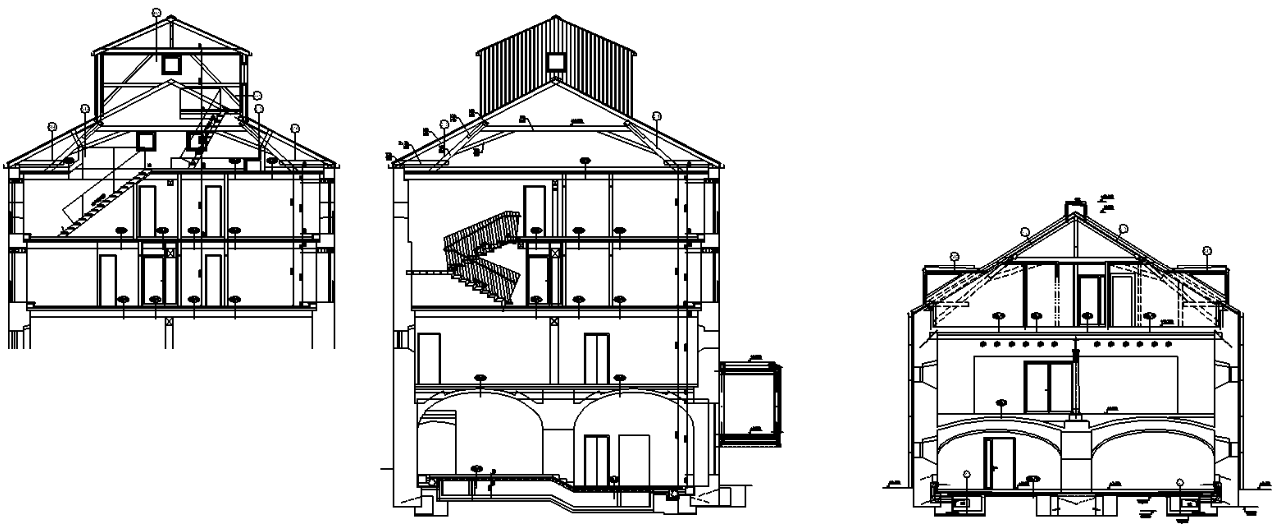


Fig. 11 Sections – situation after retrofit

6.5.2. Heating

The condensing boilers with higher investment costs, but higher efficiency than non-condensing boiler were installed in the central heating plant. In this stage a problem with the air-handling units arose. There was not much space for the air-handling units in the Brewery, and so the size of the units had to be kept as small as possible. It meant small water-to-air heat exchangers and high inlet water temperature (75°C). The water temperature returning to the heating plant would be too high for the boilers to operate in a condensing mode. Some changes in the layout of the heating system were made in order to bring the return water temperature down.

There are two condensing boilers in the central heating plant, each with the nominal output of 350 kW. Low temperature boilers convert about 93% of the calorific value of gas into usable heat. The condensing boilers employed in the heating plant can achieve as much as a 15% increase in the amount of usable heat. The average increase of 5 % is estimated to be achieved with normal operation of the heating system in the campus. If the heating system is operated in a way to maximize the effect of condensing boilers, the increase of 10% is achievable. The increase of delivered usable heat depends on the amount of condensation that take place in the boiler heat exchanger. The lower is the water temperature entering the heat exchanger the higher the usable heat. No condensation takes place above the water temperature of 50°C.

Very important changes were made on the side of the control of the heating system. The original project expected only three zones for the control of the heating system (1. cafeterias and kitchens, 2. club, auditorium and multipurpose halls, 3. accommodation services). This approach was based on the assumption that these three main areas of the building would operate independently, but rooms and spaces within these areas would be used more or less at the same time. This is not true and such approach could costs quite a lot of energy. In order to have a comfortable temperature in a student club, the auditorium and the multipurpose rooms would have to be heated to the same temperature as the club (even if they were not used). The only way to save energy would be to manually change the settings of the thermostatic valves on the radiators in the auditorium and the multipurpose rooms. The situation in the guest rooms would be even worse. If only one guest room was occupied then all the other guest rooms would be heated to the same temperature (unless the settings of the thermostatic valves in the non-occupied rooms was manually set to lower temperature).

The new way of control implemented as one of the BRITA in PuBs energy saving measure divides the Brewery into more than 40 zones with the possibility of individual control of space temperature. Space heating of the guest rooms also takes into account occupancy (card access to the rooms), opening of windows (window sensors) and ventilation (the heat output of the radiator increases when an air supply inlet in the room opens).

6.5.3. Ventilation

The installation the mechanical ventilation ductwork was a little bit of a problem in the Brewery . The ventilation ductwork is usually placed under the ceilings and suspended ceilings are used for aesthetic reasons if the ductwork is not to be visible. With many vaulted ceilings in the Brewery this approach was not applicable. The ductwork had to be placed in the under floor channels with the outlets in the wall (Fig. 12). The outlets are very close to the table (Fig. 43) what could cause the problems with the draught. Since the ventilation rate is given by requirements it is the air supply temperature that has to be kept in appropriate range to avoid draught risk.
The installation of the ductwork in the under-floor channels was only applicable on the ground floor. A different approach was adopted on the higher floors. Wall mounted nozzles are used for air distribution in the cafeteria on the second storey (Fig. 45) and in the auditorium. The air distribution ductwork suspended under the beam ceilings is used in the club.

Fig. 12 Ductwork of mechanical ventilation

The installation of the hybrid ventilation system was not without problems either. The occupancy of guest rooms changes significantly in time. In such a situation a demand controlled ventilation system meets the requirements much better than the central mechanical ventilation system. A demand controlled hybrid ventilation system was designed for the guest rooms. The control of ventilation is based on indoor air quality monitoring each guest room. There is an air supply inlet integrated in the window frame in each room and a hybrid exhaust in the bathroom. The configuration of the hybrid ventilation system is shown in Fig. 13.
The hybrid air exhaust consists of a fan, a motorized damper and a roof outlet. The T-shaped roof outlet, located in a roof ridge of a special construction, employs wind in order to increase the stack effect. The main objective of having a rather special construction of the roof ridge was to minimize the number of penetrations through the roof. All exhausts of the hybrid and mechanical ventilation systems are located in the roof ridge, because it is rather difficult to seal the opening the fibre-cement corrugated roofs used in the Brewery.

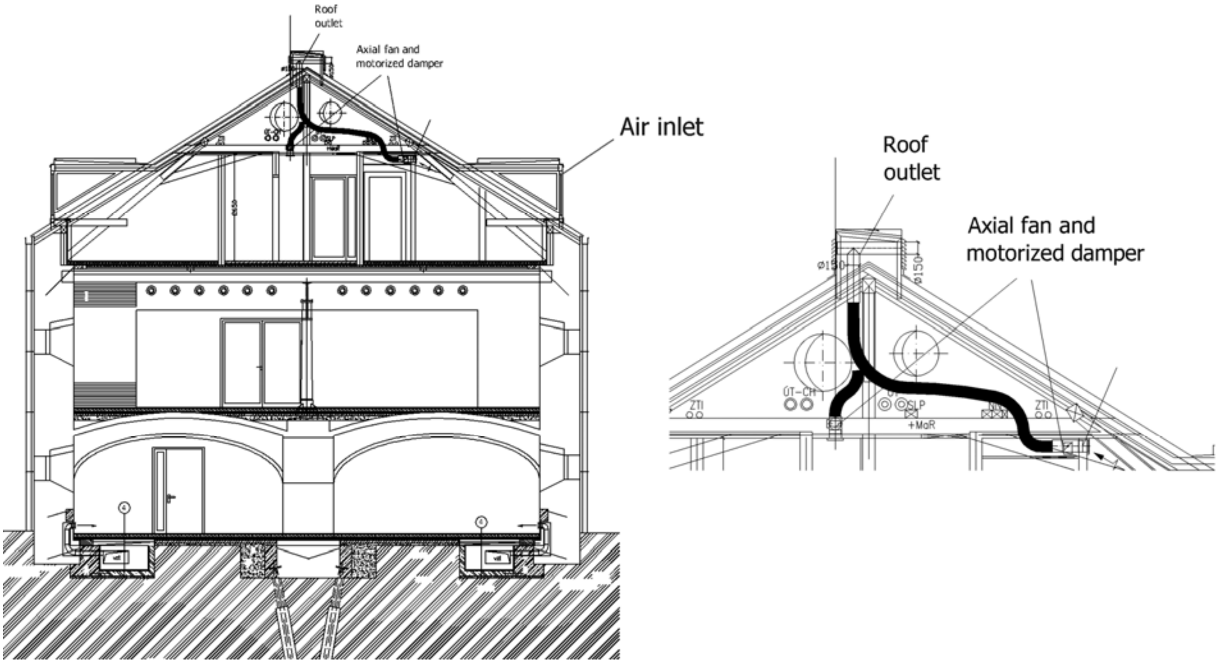


Fig. 13 Hybrid ventilation system

The control of the hybrid system is as follow, when the air quality in a room deteriorates to a certain level the air inlet opens and so does a damper in the air exhaust. If the air quality does not worsens the system works in a natural ventilation mode. If the sensor detects that the air quality gets worse the fan switches on and the system works in mechanical ventilation mode. Two ways of integration of the air inlet in the window frame are shown in Fig. 14. The integration of the inlet in the lower part of the windows is used in the guest rooms in R building (these rooms have a very thick external wall). The second photo shows the integration of the inlet in the upper part of the window that is used in the guest rooms located in the attic of the P building.

Fig. 14 Air inlets of the hybrid ventilation system

6.5.4. Cooling

Two separate cooling systems are installed in the Brewery. As mentioned in the previous paragraph the Brewery has very small windows, and so the direct solar heat gain is very

small in majority of the rooms. The heavy walls represent an advantage as far as cooling is concerned. The problems represent the internal heat gains in kitchens and cafeterias and solar heat gains in the guest rooms located in the attic of the P building. The roof is quite well thermally insulated, but it is of a timber frame construction, and does not have thermal mass to dampen the impact of solar radiation in summer.
The cooling of the cafeterias and kitchens is done by air-handling-units. The air handling units of the ventilation system are fitted with cooling coils. The cold water for the cooling coils is supplied from the central cooling plant located in the campus. The pumps for the main cooling loop are shut down in summer, because most of the buildings in the campus (including the cafeterias in the Brewery) are not used during summer break. Therefore, a Variable Refrigerant Volume (VRV) air-conditioning system had to be installed in the guest rooms that operate all year round. The VRV system are also used for heating.
The VRV system consists of 3 external units and 35 internal units. The cooling capacity of the external units is 2 x 28 kW and 1 x 40 kW. The COP in the cooling mode is 3.11 in case of 28 kW units and 2.8 in case of the 40 kW unit. The heating capacity of external units is 2 x 31.5 kW and 1 x 45 kW. The COP in the heating mode (at air temperature of 7˚C) is 3.38 in case of smaller units and 3.49 in case of the bigger one. Each of the internal units has the cooling capacity of 2.2 kW and the heating capacity of 2.5 kW. The external units located in the attic and one of the internal units in the guest room are shown in Fig. 15.

Fig. 15 External and indoor unit of the VRV air-conditioning system

The external units are (for esthetical reasons) located in the attic of the four-storey building as can be seen in Fig. 16. The outdoor air enters the attic through the opening in the facade and is blown to the outside through the vertical ducts (chimneys). The openings (covered with rain louvers) and the chimney can be seen in the picture at the beginning of the Brewery report.

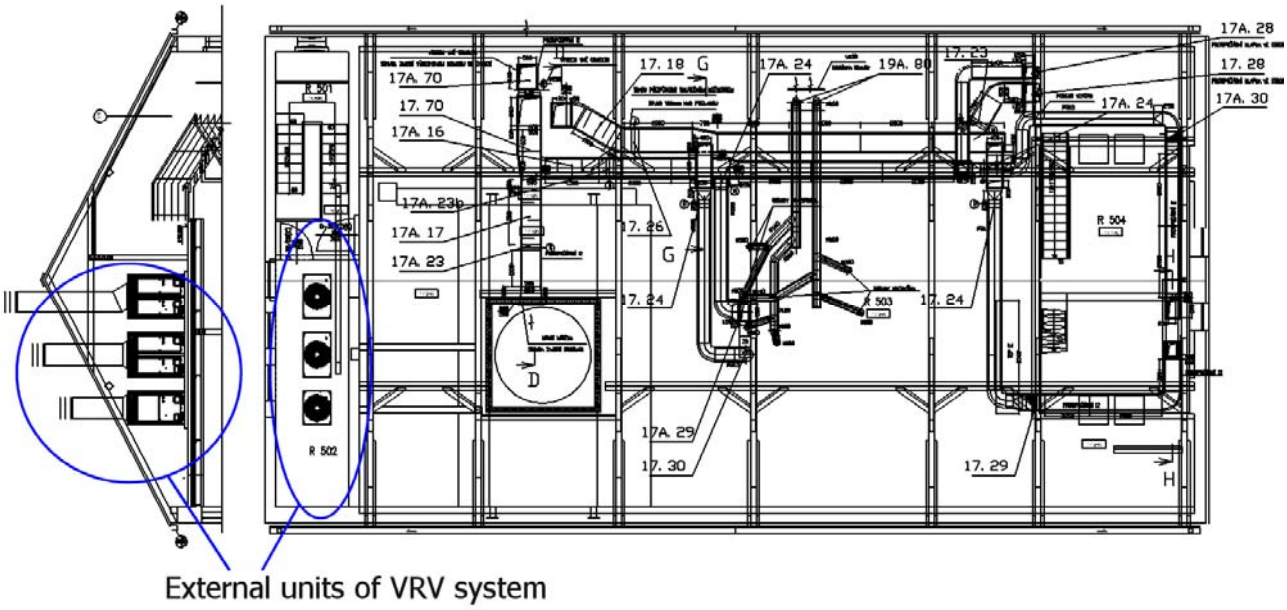


Fig. 16 Location of the external units of the VRV system

6.5.5. Lighting systems

The Brewery as an old building has quite small windows and a very small ratio between the window/glass area and the floor area. This ratio between the window area and the floor area is around 5.5 % after retrofit. It was not really possible to increase the window area since the building has 1 meter thick brick walls and there are no lintels or beams above the windows just the brick arcs/vaults as can be seen in Fig. 17

Fig. 17 Windows in the club and the corridor with sensor controlled lighting

The artificial lighting has to be used all the time in cafeterias and kitchens when these are in use. The better situation is in the guest rooms located in the attic, where dormer-windows provide sufficient amount of daylight during day.

There is a separate metering of electricity consumption for lighting in the Brewery in order to ascertain the impact of small window area. The fluorescent tubes are used for artificial lighting in order to keep energy consumption low.

The use of the light pipe skylights was considered in the corridors with no windows. This idea, however, had to be abandoned, because there was not enough space for the light pipes.

The sensor controlled lighting was installed in the corridors instead. The problem of sensor controlled lighting caused some debate because the corridors and staircases are escape routes and are supposed (for safety reasons) to be illuminated all the times.

6.5.6. Solar PV

The PV modules represent an option how to compensate the energy consumption of air-conditioning (mechanical cooling) in buildings. The Czech Republic, when implementing the EU Energy Performance of Building Directive, decided to use the reference building approach. When a building is build or retrofitted a calculation of energy consumption for a reference building is done together with the calculations of the energy consumption of an actual building. The reference building has the same geometry as the actual building, but it has the properties (e.g. U-value of the envelope) required by legislation. In order to comply with the requirements the energy consumption of the actual building has to be lower or the same as that of the reference building.
Air-conditioning (mechanical cooling) is not considered in most reference building since it is considered avoidable in the climate of the Czech Republic. If designers decide to use air conditioning (mechanical cooling) in a building, they will have to save energy somewhere else, or to compensate the consumption of mechanical cooling by means of utilization of renewable energy sources. The PV modules seem to be a good option, since there is usually a good match between the high demand for mechanical cooling in buildings and high output of the PV modules.
The total area of photovoltaic modules in case of the Brewery was reduced several times because there was not enough suitable space for their installation. The south facade of the building could be completely covered with the PV modules, but another (five storey) building is supposed to be built close the south facade in the future. This building would shade the PV modules most of the time and hence decrease the yield. The only possible option was to install the modules on the west roof of the R building. Fig. 18 shows the location of the PV modules on the roof. The peak power of the cells is 14 kW.

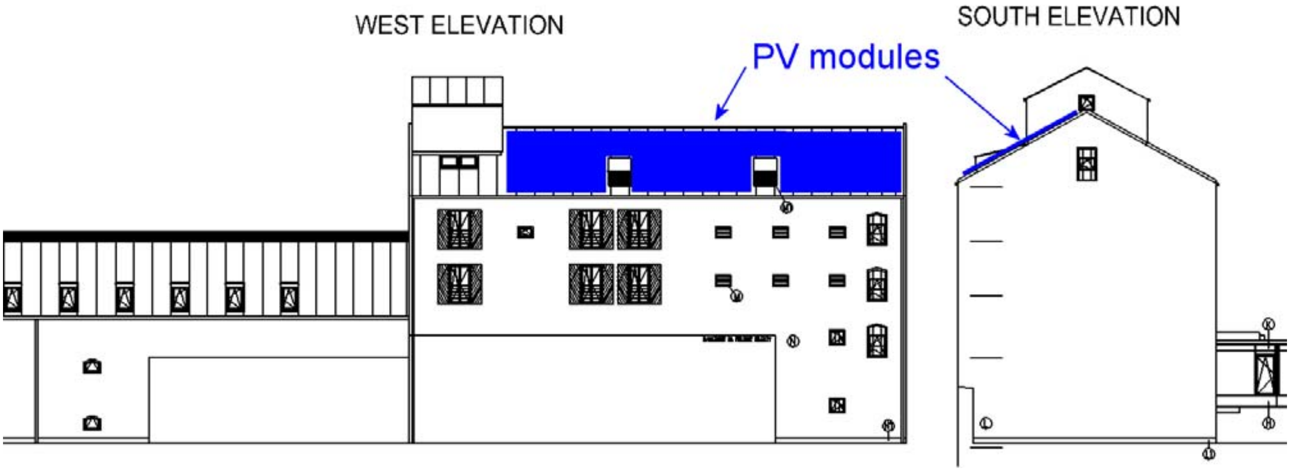


Fig. 18 Location of the PV on the roof of the Brewery

The dimensions of the modules are 1310 x 654 mm. There are 132 modules connected in an array. The details of the mounting of the modules on the fibre-cement corrugated roof of the Brewery can be seen Fig. 19.

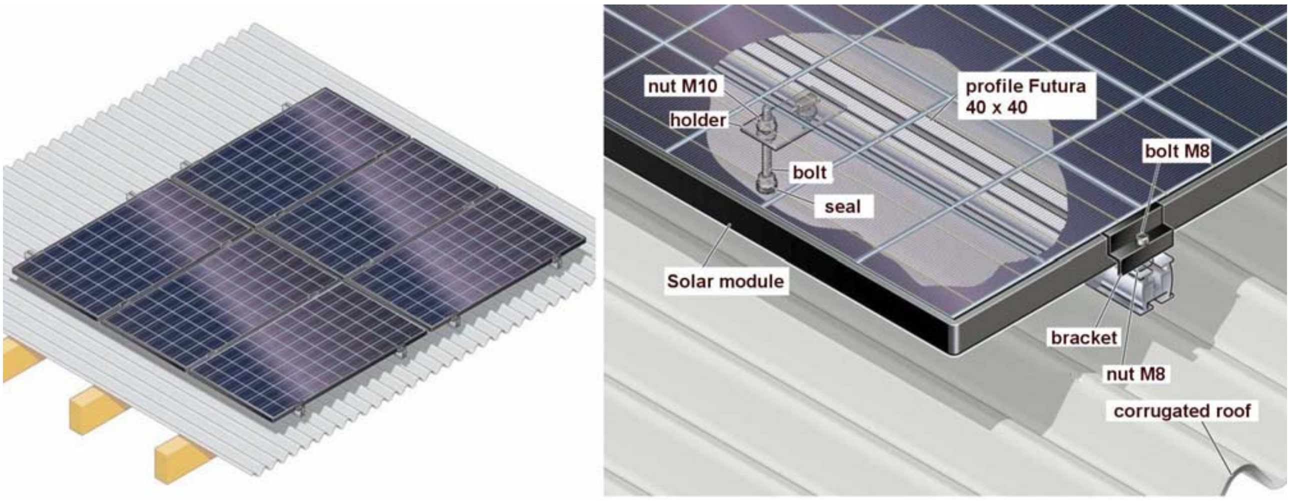


Fig. 19 Detail of the mounting of the solar modules (Donauer Solartechnik Vertriebs GmbH)

Each PV module consists of 72 cells with the cell size of 4 inches. The parameters of the modules are as follows:

Module short-circuit current at reference conditions: 3,25A
Module open-circuit voltage at reference conditions: 43,2V
Reference temperature: 25°C
Reference insolation: 1000Wm^{-2}
Module voltage at max power point and reference conditions: 34,8V
Module current at max power point and reference conditions: 3,05A
Temperature coefficient of I_{sc} at (ref. cond): +0,054%/°C
Temperature coefficient of V_{oc} (ref. cond.): -0,37%/°C
Module temperature at NOCT [°C]: 45°C
Ambient temperature at NOCT [°C]: 20°C
Module area [m^2]: 0,857 m^2

The modules are connected in three sub-arrays; two consisting of 42 modules and one of 48 modules. The sub-arrays are arranged horizontally one above another and each sub-array uses a separate inventor. This configuration offers better performance in winter when the lower part of the roof is covered with snow. The surface of modules has a very small friction and precautions had to be made in order to prevent injuries when snow slides off the roof.
The estimated power production for the modules positioned on the west roof is shown in Fig. 20. The facades of the Brewery are not oriented to due north, east, south and west, but deviate from these orientations by 11degrees. It means that the “west” roof actually has an azimuth of 259° and not 270°.

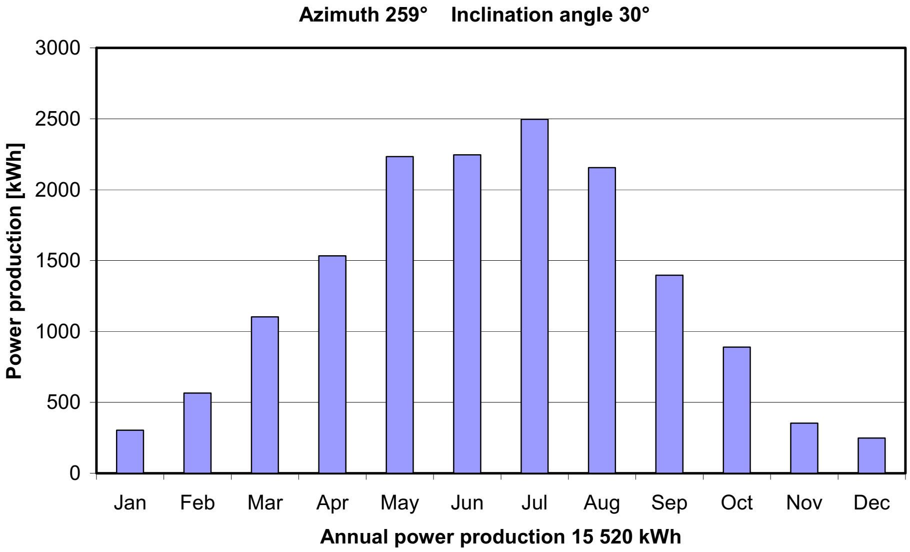


Fig. 20 Estimated yield (west roof)

If the system with the same configuration was installed on the south facade of the building the estimated yield would be lower than in case of the west roof as can be seen in Fig. 21.

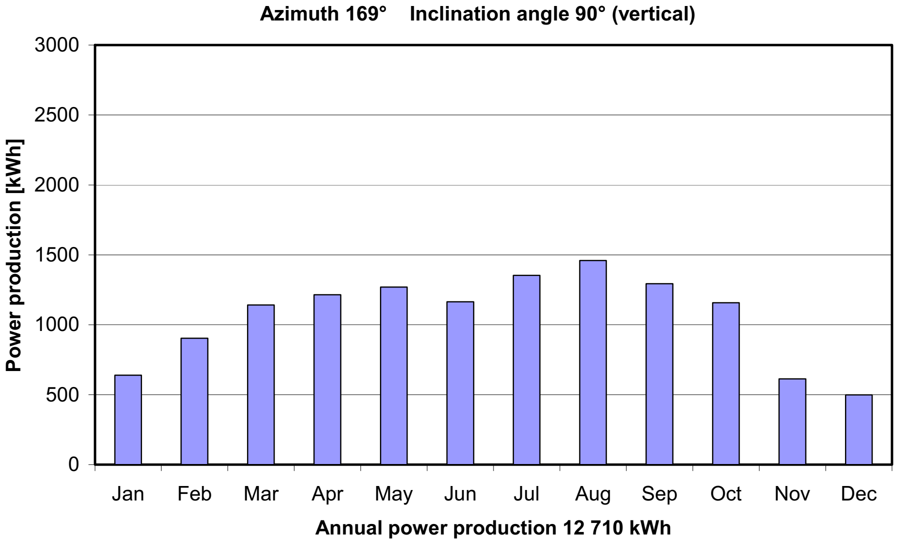


Fig. 21 Estimated yield (south facade)

The superstructure above the roof that is visible in Fig. 3 revealed itself to be very expensive to retrofit. A decision was made in the last stage of retrofit that the superstructure would be brought down. The demolition of the superstructure made space for more PV panels, but since the PV system was already ordered at that time the space remains unused (as can be seen in Fig 22). The Faculty of Information Technologies plans to order an extension to the system that would cover the rest of the roof and increase it peak output by almost 5 kW.

Fig. 22 Photovoltaic system installed on the roof of the Brewery

6.5.7. BEMS

The Brno University of Technologies requires that control and monitoring of all building systems has to be integrated into the Building Management System, whenever a new building is built or an old building undergoes major retrofitting. This approach usually brings problems with the compatibility of the communication protocols used by different systems but offers and advantage of central data storage and access to the data from any computer connected to the internet.

In case of Brewery the integration involved:

- control and monitoring of heating, ventilation and air-conditioning
- monitoring of heat consumption
- monitoring of consumption of electricity
- monitoring of water consumption
- monitoring of natural gas consumption
- monitoring of indoor air temperatures
- electronic security system
- fire alarm system
- access system
- Closed Circuit TV
- parking system

Another requirement on the BMS arising from the BRITA in PuBs project was the implementation of the central control system of the “smart” building type in order to:

- achieve satisfaction of the occupants with the indoor conditions in an energy efficient way
- control and monitor energy flows in order to optimize energy consumption

The schematic of the Building Management System is in Fig. 23. Two main communication protocols are used in the system – TCP/IP and LONWORKS®.

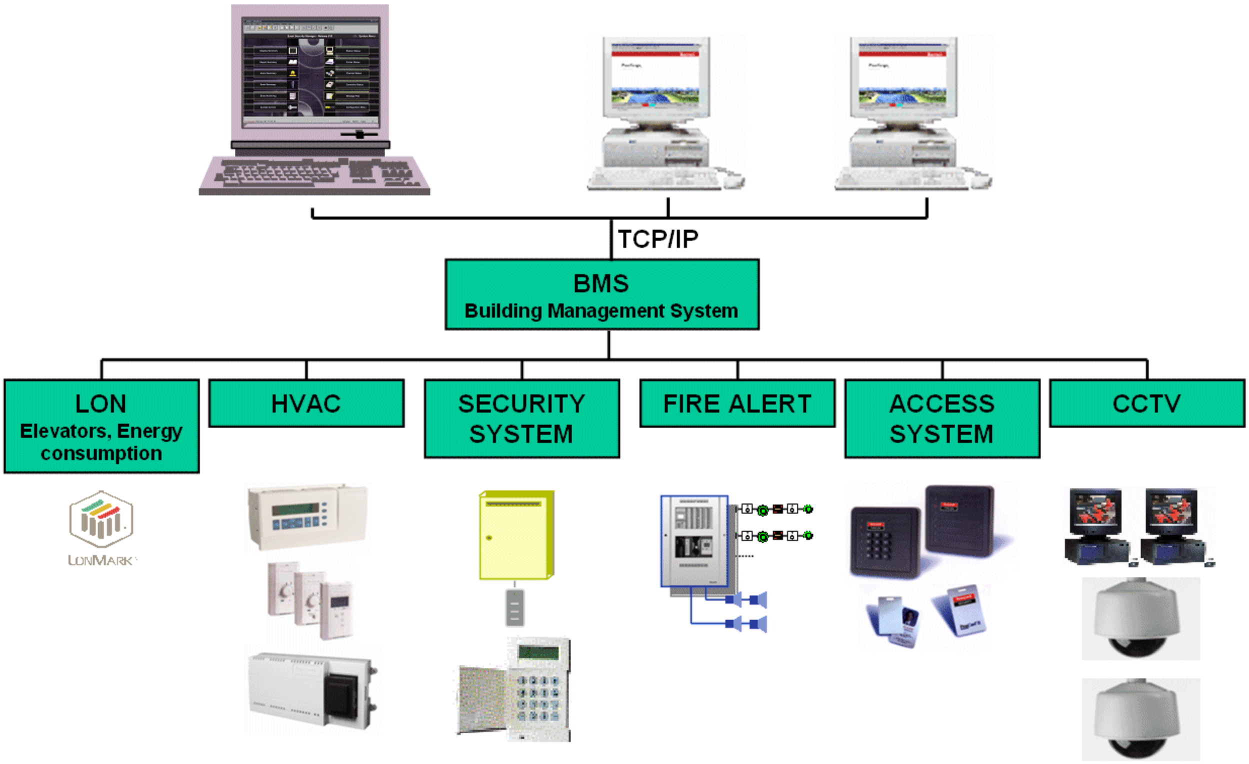


Fig. 23 The BMS system

The data acquisition is based on the LONWORKS® technology. With this approach it is possible to acquire data from heat meters, water meters, electricity meters, and other devices that use the communication protocol. The above mentioned philosophy of having one BMS in the whole campus had a huge impact on the energy saving measures implemented within the framework of the BRITA in PuBs project. It was not possible to design building systems as “stand alone” systems, but it was necessary to integrate their control and monitoring into the BMS. This did not have a negative impact on the costs of the systems themselves, but caused some delays in the design process and also increased the design costs. The BMS offers a very comfortable access to the building systems and their operation (e.g. air handling unit in Fig. 24)

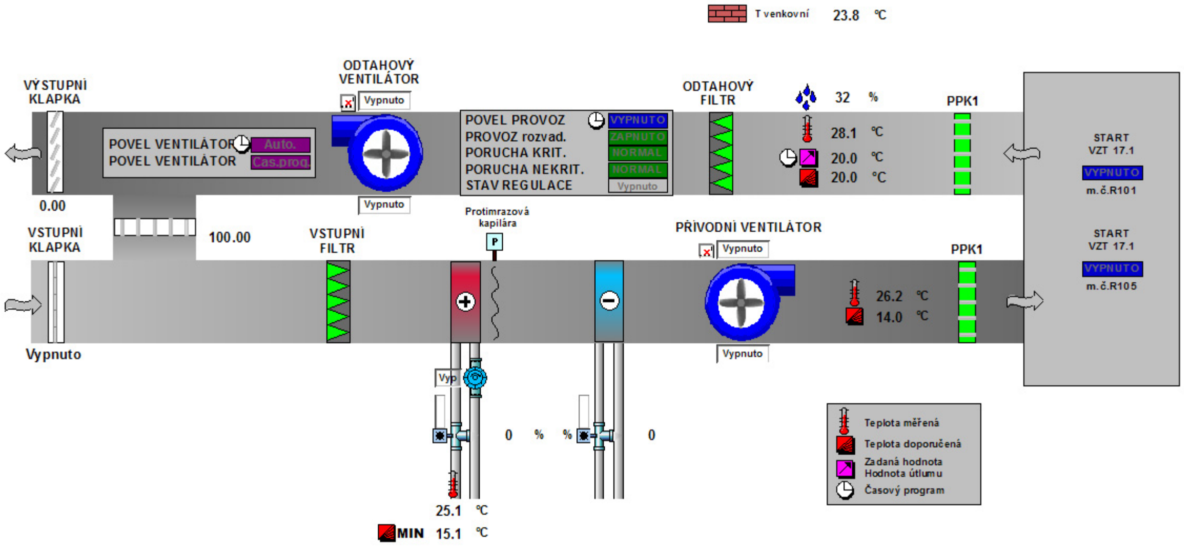


Fig. 24 Monitoring of the air handling unit

The biggest problem with the BRITA in PuBs energy saving measures was the control of the hybrid ventilation system. The manufacturer offers an interface for the communication with a "superior" control system (BMS), but this interface does not allow direct control of the ventilation system by that "superior" control system. This approach was not acceptable and the hybrid system was designed from scratch.
The central control and monitoring brings also some advantages. The individual control of heating in nearly all room in the Brewery means that there are temperature sensors in all of those rooms. With all the sensors connected to the BMS monitoring of temperatures will be an easy task, which does not require extra monitoring equipment.

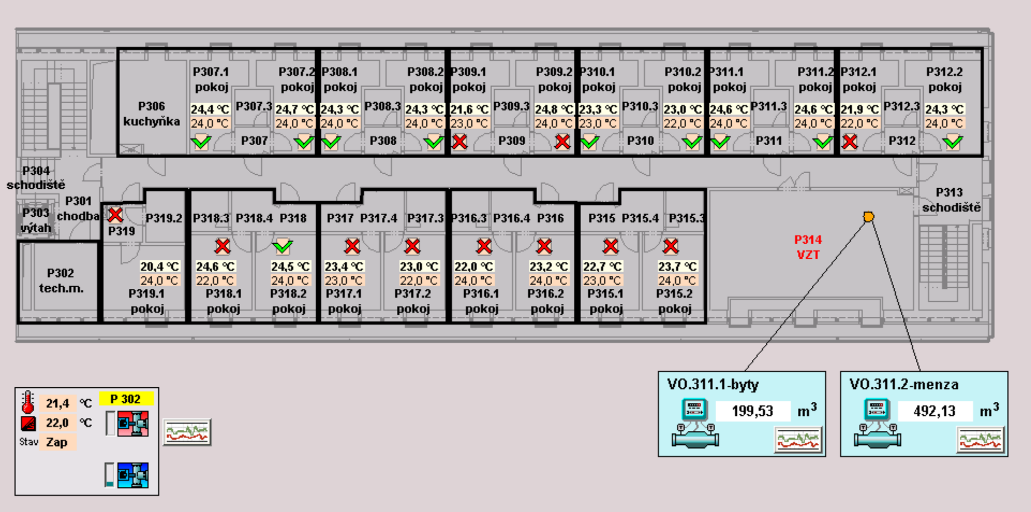
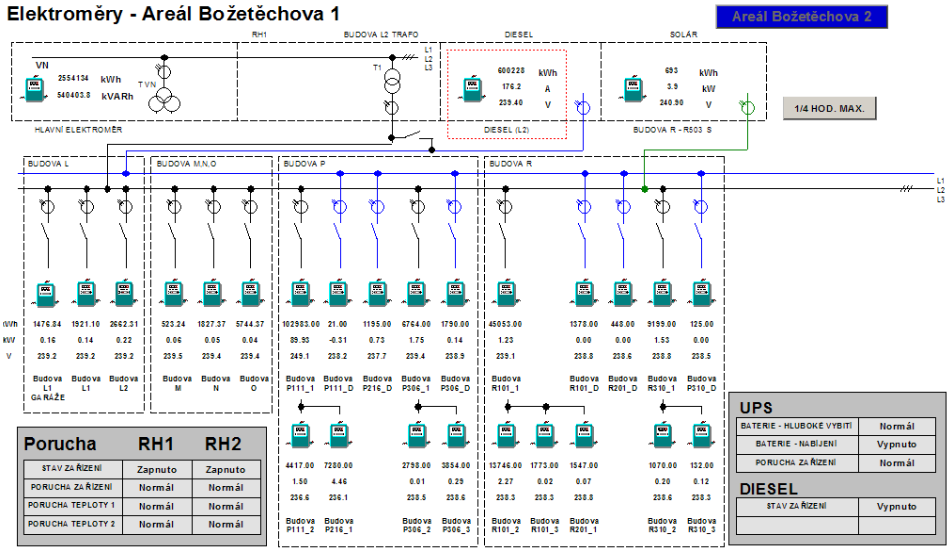


Fig. 25 Monitoring of the guest rooms

In order to get more representative data about the consumption of electricity a decision was made to measure separately the consumption of electricity for lighting and for the VRV air conditioning system. The separate measurement of the consumption of the VRV air conditioning system makes it possible to study how well the production of electricity by the PV cells (which is monitored separately) matches the consumption of the VRV system. It looks like a good idea for future to employ PV modules as compensation for electricity consumption of air-conditioning systems.



Porucha	RH1	RH2
STAV ZAŘIZENÍ	Zapnuto	Zapnuto
PORUCHA ZAŘIZENÍ	Normál	Normál
PORUCHA TEPLOTY 1	Normál	Normál
PORUCHA TEPLOTY 2	Normál	Normál

UPS

BATERIE - HLUBOKÉ VYBITÍ	Normál
BATERIE - NABÍJENÍ	Vypnuto
PORUCHA ZAŘIZENÍ	Normál

DIESEL

STAV ZAŘIZENÍ	Vypnuto

Fig. 26 Electricity meters in the BMS

6.6. Monitoring

As mentioned earlier all sensors and meters used for the monitoring of the Brewery has been connected to the Building Management System (BMS) of the campus of the Faculty of Information Technologies. This approach allowed to decrease the number of sensors, since some sensors used for control can also be employed for monitoring. Moreover, all the data have the same format, sampling rates, etc. what makes their processing much easier.

6.6.1. Monitoring plan

A good monitoring plan is crucial for the appropriate interpretation of the results. It is important to keep in mind that operation of a building (user profile) can change over the time. The changes in building usage profile have an impact on energy consumption of the building. The results of monitoring can then differ from the expected results. Some changes of the user profile occurred also in case of the Brewery. It was expected that there would be 2 cafeterias in the building - one for the students and the other for the academics. The cafeterias were supposed to be open from 10 A.M. to 4 P.M. Finally, one of the cafeterias operates as a regular restaurant with the opening hours 11 A.M. to 8 P.M. The restaurant (named Stary Pivovar – Old Brewery) is open to general public.

A relatively high number of parameters can be monitored due to the integration of the monitoring of building services into the Building Management System:

- Monitored parameters
  - Electricity consumption (19 meters)
    - Consumption
    - Voltage
    - Electric current
    - Power factor
  - Heat consumption (7+2 meters)
    - Heat
    - Temperature drop
    - Flow
    - Heating/Cooling capacity
  - Water consumption (4 meters)
  - Local Weather
    - Outdoor temperature (3 sensors)
    - Solar radiation (solar sensor)
    - Wind speed and direction
  - Thermal Comfort
    - Air temperature (42 sensors)
  - Indoor Air Quality (33 sensors)
  - Photovoltaic system
    - Power output
    - Voltage
    - Electric current
  - Other monitored parameters
    - Opening windows
    - Operation of air handling units (on/off, air temperature and humidity)
    - Operation of VRV air-conditioning (heating/cooling)
    - Access of occupants in the gust rooms

6.7. Data analysis

6.7.1. Local Weather

Calculations of energy consumption for space heating and cooling of a building are usually done using meteorological data that reflect a long period of time (usually 30 years or more). The calculation performed with such meteorological data (e.g. Typical Meteorological Year) provide much better picture of the energy performance of a building during its lifespan than the calculations done for the extremely cold or warm year. The same approach applies for the measured consumption. The year-to-year fluctuations in the energy consumption of a building are partially caused by climatic conditions. It is therefore necessary to know the local weather conditions during the measured year in order to adjust (normalize) the energy performance of a building.

Outdoor temperature is measured at three locations at the Brewery. Unfortunately, the sensors were not shielded against solar radiation and therefore showed quite high temperatures on sunny days. Fig. 27 shows the outdoor temperature measured by the sensors in January 2008. As can be seen the readings of the sensors differ from each other on sunny days.

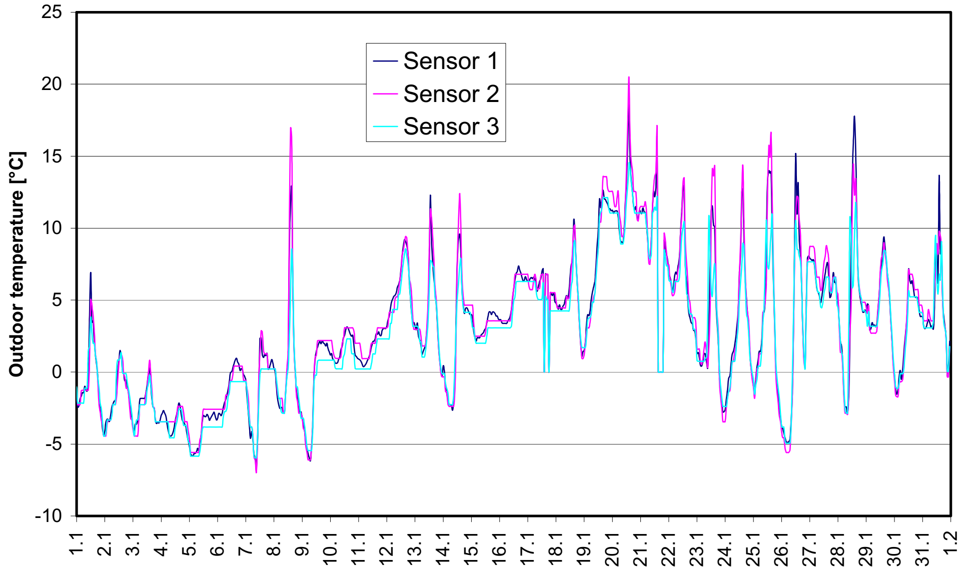


Fig. 27 Outdoor temperature in January 2008

6.7.1.1 Energy Demand: Electricity

There are 19 electricity meters installed in the Brewery. In spite of such a high number of meters it is not possible to break down the electricity consumption to every means of use. The electricity consumption for artificial lighting (including the backup system), VRV air conditioning and kitchens is measured separately. The results of the monitoring for the time period from April 1, 2007 to March 31, 2008 can be seen in Table 8.

Table 8 Consumption of electricity

	[kWh/m^{2}a]	Total annual (kWh)
Artificial lighting	8.6	22 763
Kitchens and cafeterias	21.7	57 807
VRV air-conditioning	4.8	12 700
Total electricity	**47.4**	**126 114**

The pie chart in Fig. 28 shows the break down of electricity consumption in percents. It is obvious that kitchen appliances account for most of energy consumption in the Brewery. The cafeterias themselves contribute to the consumption very little since there are no electrical appliances in cafeterias and artificial lighting is measured separately.

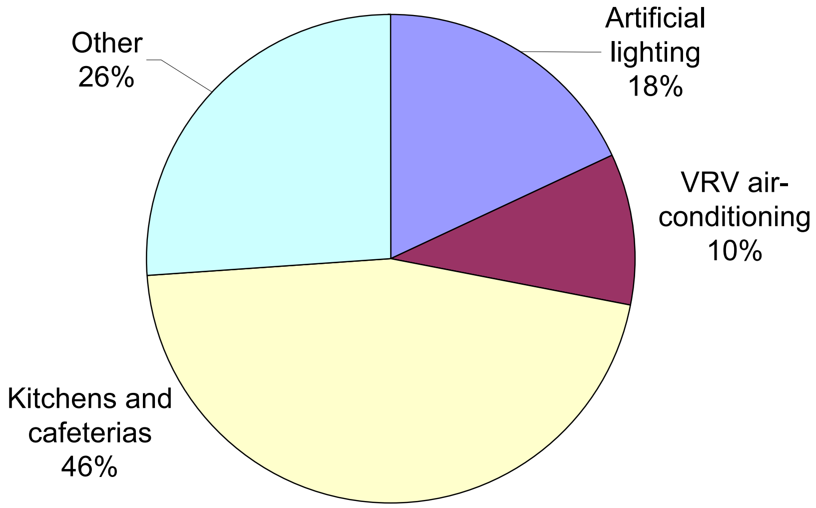


Fig. 28 Break down of electricity consumption

Fig 29 shows the one-hour averages of total power consumption in March 2008. It can be seen that peaks of power consumption reached to almost 120 kW and that total consumption rarely fell bellow 20 kW. It is also apparent that most of electricity is consumed in kitchens that only operate on week days.

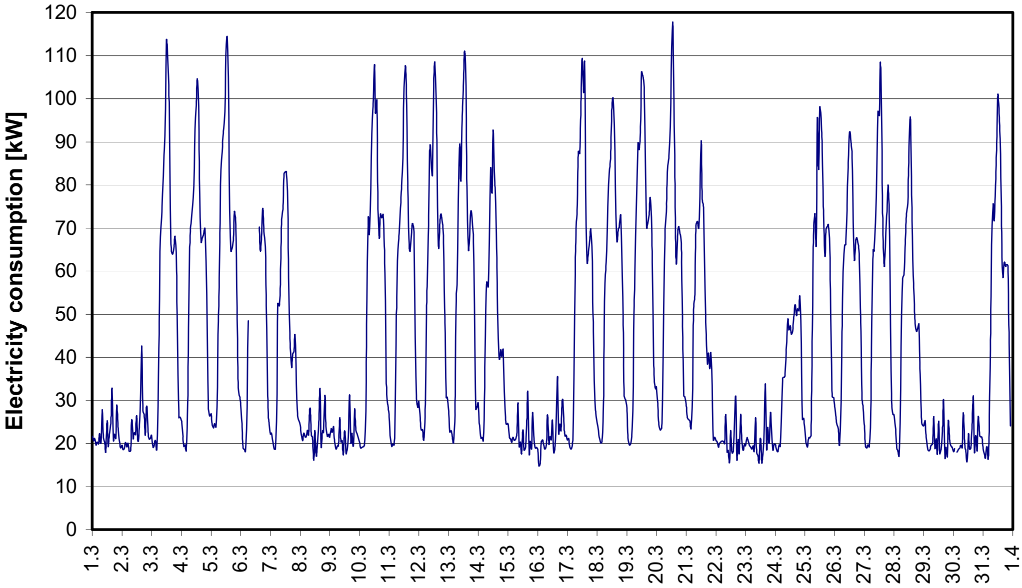


Fig. 29 Total power consumption in March 2008

Fig. 30 shows the power consumption for artificial lighting in March 2008. The maximum power consumption for artificial lighting exceeded 10 kW on March 19. The Brewery has very small windows and artificial lighting is needed all the time in some spaces (when these are in use).

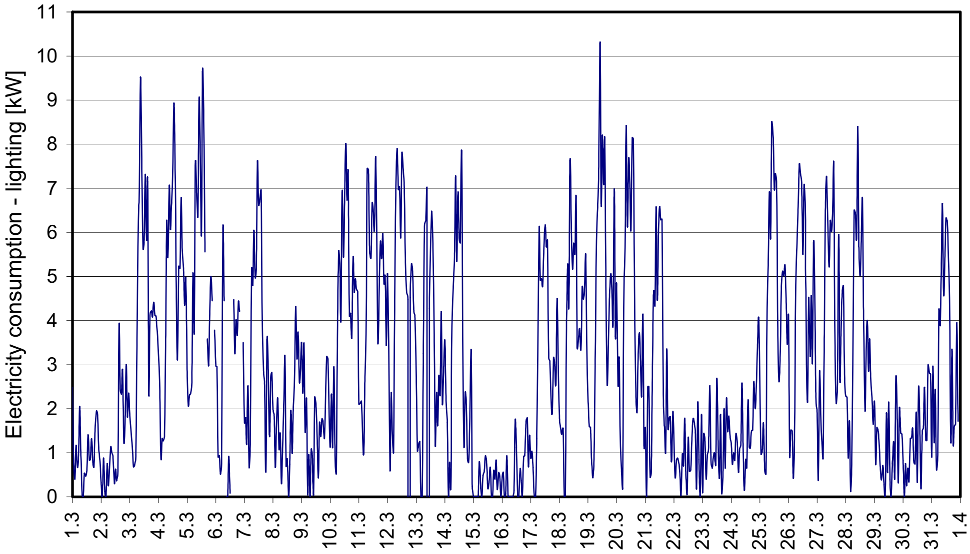


Fig. 30 Consumption of electricity for artificial lighting (March 2008)

The total consumption of electricity before the retrofit was estimated at 164 000 kWh/year (Table 3). As can be seen in Table 5, the total predicted savings of electricity amounted 51 500 kWh. The total measured consumption, after the production of the photovoltaic system (11 232 kWh) was subtracted, was 114 882 kWh/year or 43.2 kWh/m^2 year. It means that real total savings of electricity were 49 118 kWh/year (some 5% short of the prediction). The reasons will be discussed at the end of the report.

6.7.1.2 Energy Demand: Thermal

There are 9 heat meters installed in the Brewery. Seven of the heat meters measure heat consumption for heating, domestic hot water heating, and ventilation and two heat meters measure consumption of cooling. The measured consumptions of heat for the time period from April 1, 2007 to March 31, 2008 are in Table 9.

Table 9 Measured heat consumptions

	[kWh/m^{2}a]	Total annual [kWh]
Space heating (guest rooms)		61 151
DHW (guest rooms)		33 762
Space heating (building P except of guest rooms)		58 623
Space heating (building R except of guest rooms)		57 341
Ventilation (multi-purpose rooms)		42 111
Ventilation and DHW (cafeterias and kitchens)		150 411
Total consumption of heat (heating, ventilation, DHW)	**151.7**	**403 398**

The pie chart in Fig. 31 shows the break down of heat consumption. Unfortunately, heat consumption for ventilation and DHW in cafeterias and kitchens is measured together. Both, air handling units and the heat exchangers for DHW use water with the temperature of 75°C.

A loop with lower water temperature is used for space heating in order to make the condensing boilers work more effectively.

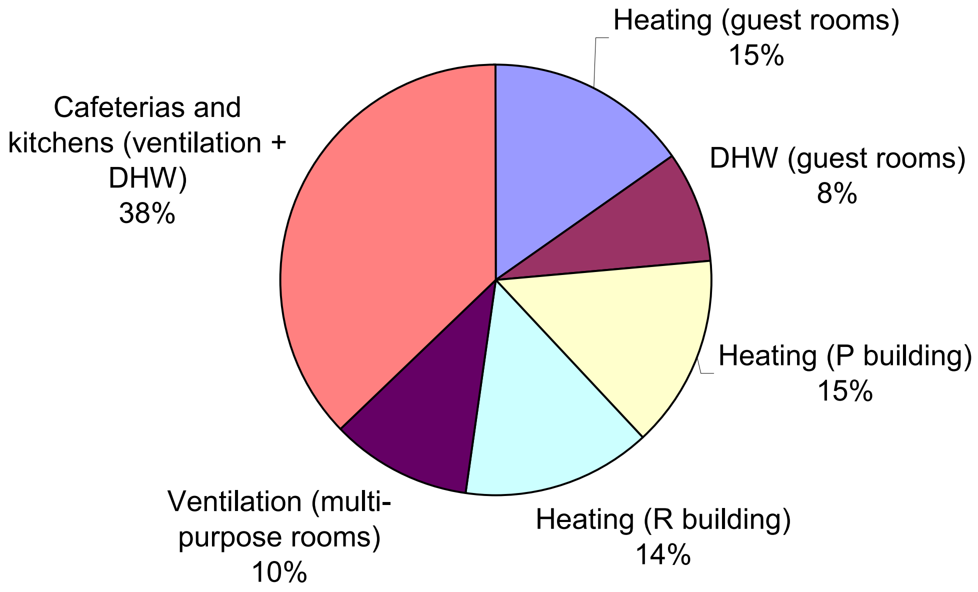


Fig. 31 Break down of heat consumption

The values of measured heat consumption in Table 9 are not divided according by the means of use (consumption of heat for space heating, DHW and ventilation). The problem is that heat consumption for ventilation and DHW in cafeterias and kitchens is measured together. Since water consumption in cafeterias and kitchens is also monitored a rough estimate of the total consumption of energy used for DHW heating and ventilation can be produced. If we suppose that the ratio of the DHW consumption to the total water consumption is the same for cafeterias and the guest room we can assume that the heat consumption for DHW in the cafeterias will be proportional to total water consumption. That way we can calculate (estimate) the amount of heat that was used for DHW and ventilation in the kitchens and cafeterias.

Table 10 Consumption of heat (by means of use)

	[kWh/m^{2}a]	Total annual (kWh)
Total space heating (measured)	66.6	177 116
Total DHW (estimated)	27.9	74 172
Total ventilation (estimated)	57.2	152 111
Total consumption of heat	**151.7**	**403 398**

The total heat consumption for space heating in the whole building was measured and it is relatively low. However, space heating system only covers part of the thermal losses. Most of the ventilation losses and part of the transmission loss is covered by ventilation system. The total consumption of heat for heating the building is the sum of heat used for space heating and ventilation and it is 329 227 kWh/year or 123.8 kWh/m^2 year. The estimated consumption of heat for space heating and ventilation before the retrofit can be found in Table 3 and the predicted savings can be found in Table 5. The total consumption of heat for heating the Brewery before the retrofit was estimated at 660 000 kWh/year. The floor area before the retrofit was 2 300 m^2. It means that the consumption per square meter of floor area was 287 kWh/m^2 year. The achieved savings are 330 773 kWh/year or 124.4 kWh/m^2 year.

Although the predicted savings of 380 500 kWh have not been reached the total consumption of heat for heating the Brewery was reduced by 50 %.

6.7.1.3 Contribution from Renewables

The only renewable source of energy at the Brewery is the photovoltaic system. The system is located on the west roof and it reaches the peak production is the afternoon when the sun moves to the south west. Fig. 32 shows the solar radiation intensity incident on the surface of the PV panels and the power output of the system in March 2008. The insolation sensor that is used for measurements of solar radiation intensity is a very simple one and it is rather insensitive to diffuse radiation.

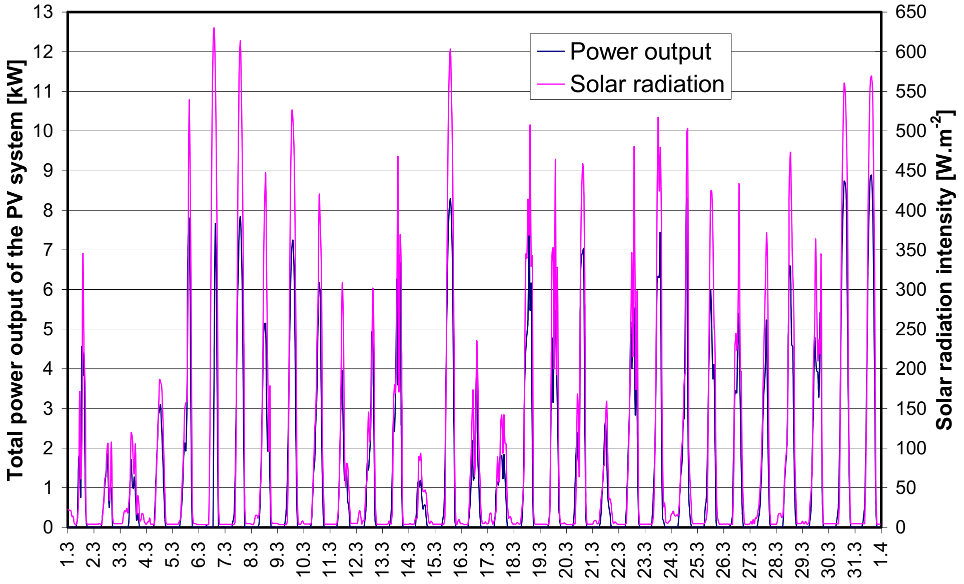


Fig. 32 Power output of the PV system in March 2008

The chart in Fig. 32 was plotted using one-hour averages of power production and solar radiation intensity. This approach is suitable when we try to cover long periods of time. For the analysis of the system performance during the day it is useful to use one-minute values. The chart of the performance of the system on a sunny spring day (March 15, 2008) is shown in Fig. 33.

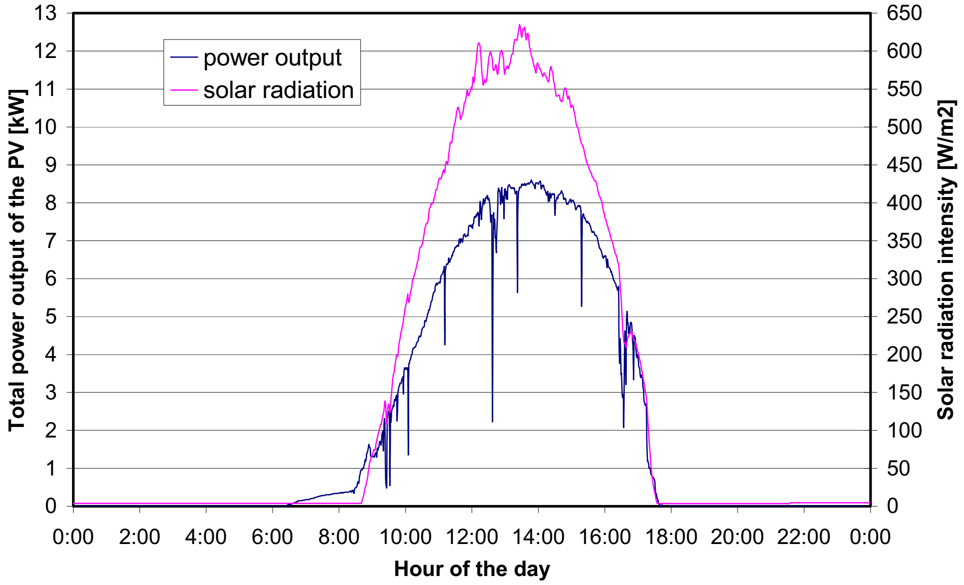


Fig. 33 Power output of the PV system on March 15, 2008

There were some problems with the monitoring of the PV system in the beginning. The electricity meter did not communicate with the BMS because of the incompatible communication protocol. Only manual reading of the meter was possible, which was very inconvenient. The electricity meter was replaced on August 6, 2007 and it has been connected to the BMS since August 8, 2007. The chart in Fig 34 shows the monitored and simulated month-by-month production of electricity of the PV system. The power production in August 2007 is for the time period between August 6 and August 31. The PV system had produced 6 258 kWh by August 6, 2008. The simulations were done for the Typical Meteorological Year in the city of Brno what probably accounts for much of the differences. Some simplification of the PV system was also necessary in order to perform the simulations. The electricity production of the PV system depends very much on the load to the system. The PV system should always work in the maximum power point in order to get the maximum yields. The power point trackers are being used in order to optimize the performance of the PV systems, but these behave differently in the simulations and the real life.

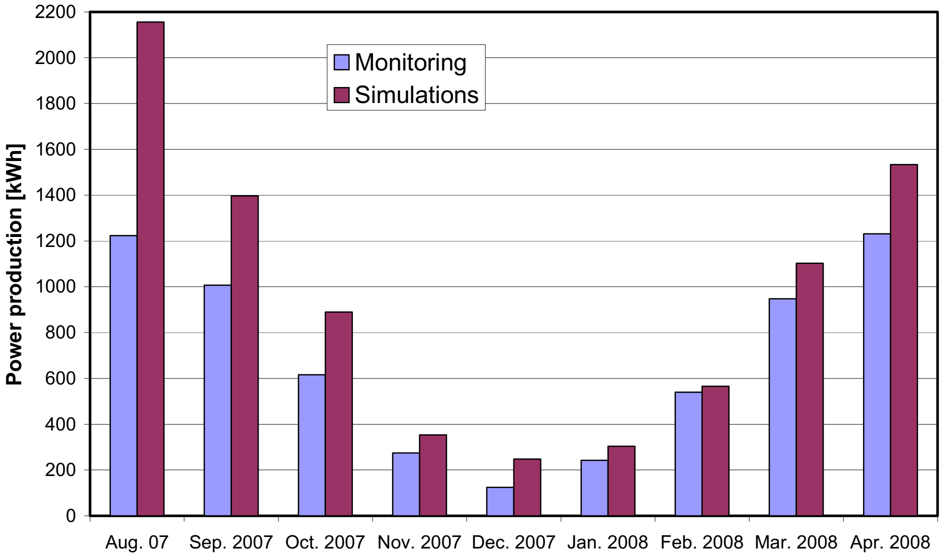


Fig. 34 Comparison of measured power production with the simulations

Total amount of electricity produced by the PV system between April 1, 2007 and March 31, 2008 was 11 232 kWh what is less than 15 520 kWh predicted by the simulations.

Table 11 Electricity produced by the photovoltaic system

	Total annual	Renewable fraction
PV	11 232 kWh	0.089

The fraction of the electricity produced by the PV system to the total consumption of electricity in the Brewery is 8.9 percent. The fraction could increase over 10 percent when the solar cells cover the whole area of the roof.

6.7.1.4 Water consumption

No water saving measures were applied at the Brewery within the framework of the BRITA project. The Brewery does no have an external supply of DHW. The DHW is heated at the site by heat exchangers using the water from the high temperature loop. An air-to-water heat pump is used to prepare DHW in the club in summer when the main heating plant is shut down. The cool air from the heat pump is supplied to the club and thus contributes to space cooling in summer.

The separate measurements of water consumption for the cafeterias, guest rooms and the club are installed in the Brewery. Table 12 shows water consumption in the monitoring period (April 1, 2007 to March 31, 2008). As could be expected, the cafeterias and kitchens account for most of water consumption.

Table 12 Water consumption

Total	0.59 m^3/m^2a	1 570 m^3/a
Cafeterias and kitchens		835.1 m^3/a
Guest rooms		697.7 m^3/a
Club		37.1 m^3/a

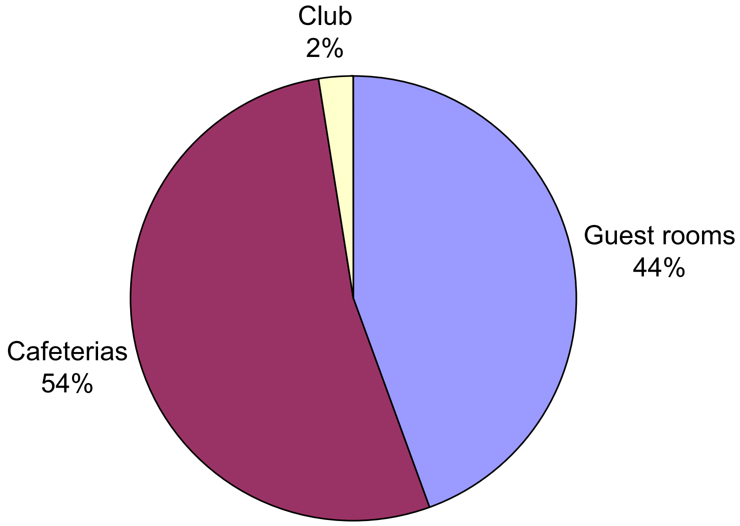


Fig. 35 Break down of water consumption

The Brewery was commissioned at the end of March 2007, almost at the end of the academic years. It therefore began to operate in the last week of September 2007 with the beginning of the academic year 2007/2008. The monthly consumptions of water are in Fig. 36.

As can be seen, water consumption was quite low in summer 2007 (there were no occupants in the building). The general contractor did not deliver all the furnishings and the equipments of the Brewery. The investor (Brno University of Technology) arranged the furnishing of guest rooms, clubs, multi purpose halls and cafeterias (some kitchen equipment included). Water consumption in summer was therefore related to commissioning of cafeterias and guest rooms and also to final building cleaning before the operation.

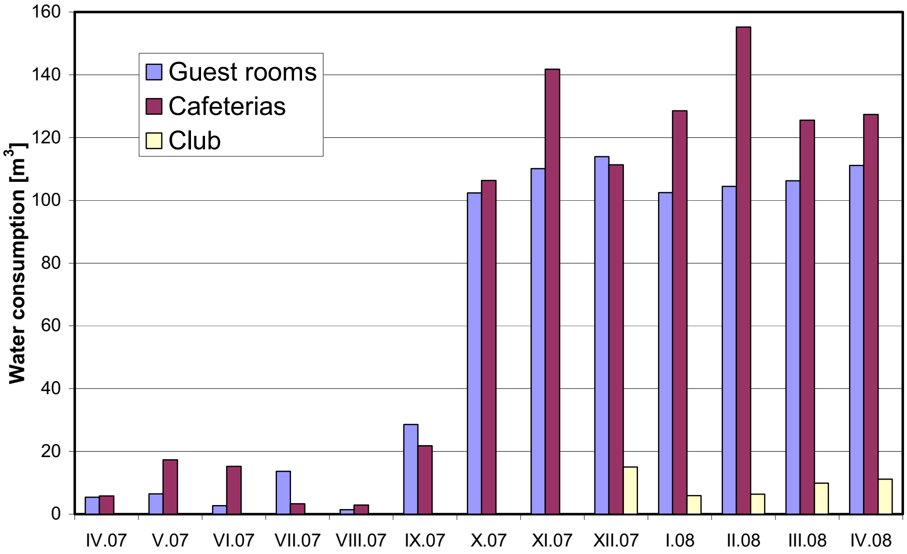


Fig. 36 Monthly water consumption

6.7.1.5 Primary energy calculation

The primary energy can be obtained by multiplying the actual energy consumption by the primary energy factor. The Czech Republic produces most of its electricity in coal-fired power plants and the primary energy factor for electricity is considered to be around 2.8 for electricity of 400 Volts. It means that 2.8 kWh of primary energy is used in the power plants in order the final user could get 1 kWh from the local 400 V grid connection. The primary energy factor for heat (condensing boilers burning natural gas) is considered 1.1.

Table 13 Primary energy consumption

		Total for the whole building
Heat (space heating)	73.2 kWh/m^2 a	194 828 kWh/a
Heat (ventilation)	62.9 kWh/m^2 a	167 322 kWh/a
Heat (DHW)	30.7 kWh/m^2 a	81 589 kWh/a
Electricity	120.9 kWh/m^2a	321 670 kWh/a

6.7.2 Thermal comfort

The level of thermal comfort is generally a function of several parameters (air temperature, mean radiant temperature, relative humidity and air velocity). It is almost impossible to measure all the parameters over a long period of time. Air temperature is, in most cases, the most important parameter influencing thermal comfort. The mean radiant temperature plays a crucial role when surface temperatures differ very much from the air temperature. This is the case when radiant heating or cooling is used or when the building envelope has low insulating properties leading to low surface temperatures. No radiant heating or cooling is used in the Brewery and the glazing area (that usually has low radiant temperature) is very small. It can therefore be expected that mean radiant temperature is very close to air temperature in most of the rooms. The relative humidity has only a small impact on thermal comfort unless it is very high (close to RH = 100%) and thus limiting sweat evaporation. Except of the certain parts of the kitchens it is not a case in the Brewery.

The air temperature sensors are installed in all the rooms where people stay. The sensors are connected to the Building Management system and the values of temperatures are recorded in 1 minute intervals. The most sophisticated control and monitoring is installed in the guest rooms. The windows are fitted with the contacts which allow to monitor window opening. Heating and cooling shuts down when a window is opened. However, even the most sophisticated approach cannot prevent users from foiling the energy-efficient operation of the system. The guest rooms are also equipped with the hotel-type card slots where the occupants insert a card after their arrival. When the card is inserted the room heating is set to the thermal comfort setpoint and the artificial lighting is enabled. When the card is removed the heating goes to a lower heating setpoint (e.g. 15°C) and all the lights are switched off. Unfortunately, the card slot is not a card reader and by inserting just a piece of paper into a slot occupants can disable this energy saving measure. Fig. 37 shows the air temperature and window opening in one of the guest rooms in January 2008. As can be seen, the occupant opened the window on January 1, 2008 and left it open for three days. There is a safety measure programmed in the BMS, which only allows the room temperature to drop to a certain value when the window is open and then the heating system kicks in to prevent the possible damage from freezing. It is cheaper to waste some heat with an open window than to let the heating system and water piping freeze and thus cause an expensive damage to the building.

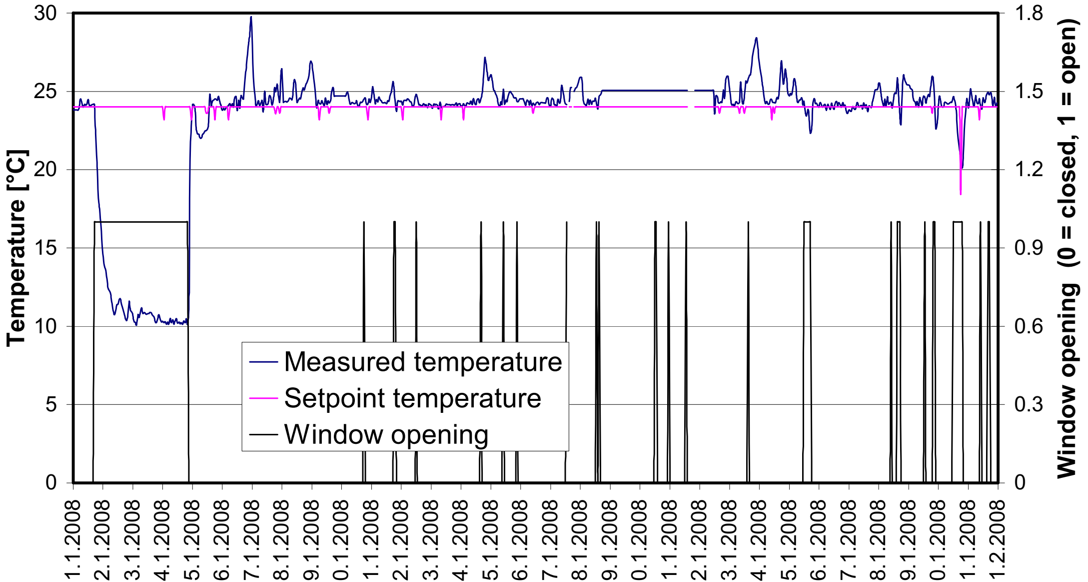


Fig. 37 Air temperature and window opening in one of the guest rooms

6.7.2.1 Cumulative frequencies of temperatures

The cumulative temperature distributions in 15 rooms in the Brewery will be shown in this sub-chapter to document the indoor conditions in the Brewery in the heating season 2007/2008. The chart of cumulative frequencies is an easy to read demonstration of temperature distribution over a certain time interval. The time interval for all the rooms is from September 1, 2007 to April 30, 2008.

Guest rooms in the attic of the P building

There are 21 guest rooms on the third storey of the P building. Every guest room has an individual control of heating cooling and ventilation. Fig. 38 show the screen shot of the Building Management System (BMS) where the green tick marks indicate that the rooms was currently occupied the red crosses indicate that the room was not currently unoccupied. The upper temperature reading (box) is the actually measured air temperature in the room and the lower temperature box is the setpoint temperature.

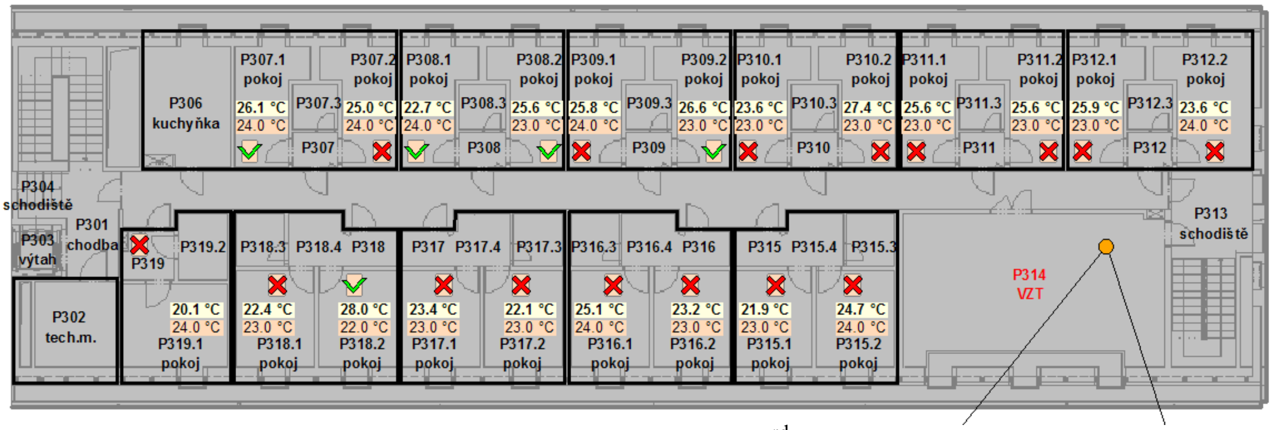


Fig. 38 BMS screen shot of the attic with guest rooms (the 3rd storey of the P building)

The chart in Fig. 39 shows the cumulative frequencies of temperatures in several guest rooms in the P building in the time period from September 1, 2007 to April 30, 2008. The attic is of timber-frame construction (low thermal mass) and the spread of temperatures is quite wide.

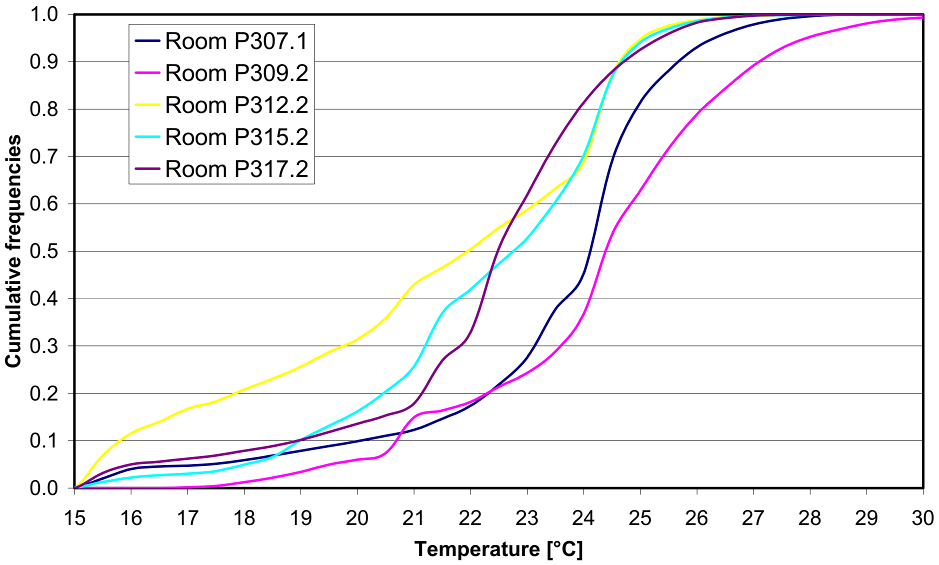


Fig. 39 Cumulative frequencies of temperatures in attic guest rooms

Fig. 40 shows the BMS screen shots of the third and the fourth story of the R building. There are six guest rooms on each floor.

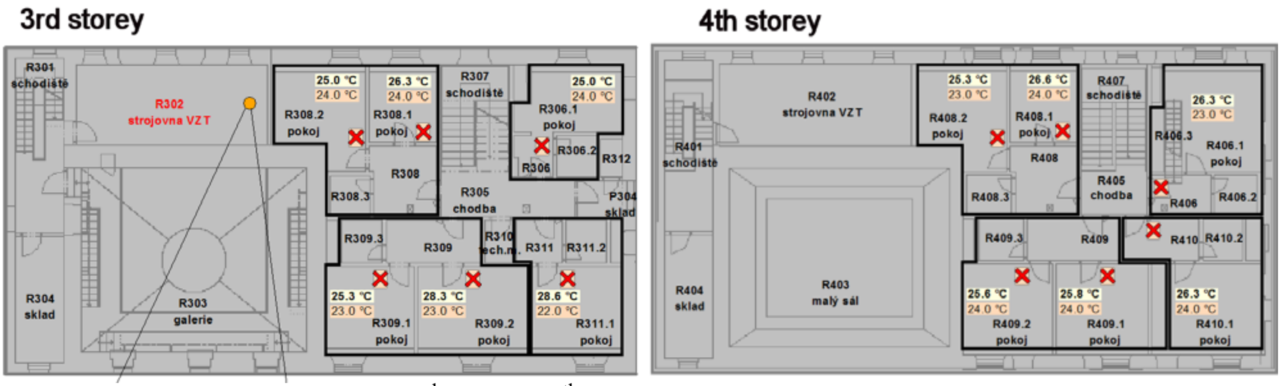


Fig. 40 BMS screen shot of the 3rd and the 4th storey of the R building

The external walls of the guest rooms in R building are made of red brick and they are 1 meter thick. This means a huge amount of thermal mass which has a stabilizing effect on the air temperature inside the rooms. The chart in Fig. 41 shows the cumulative frequencies of temperatures in four guest rooms.

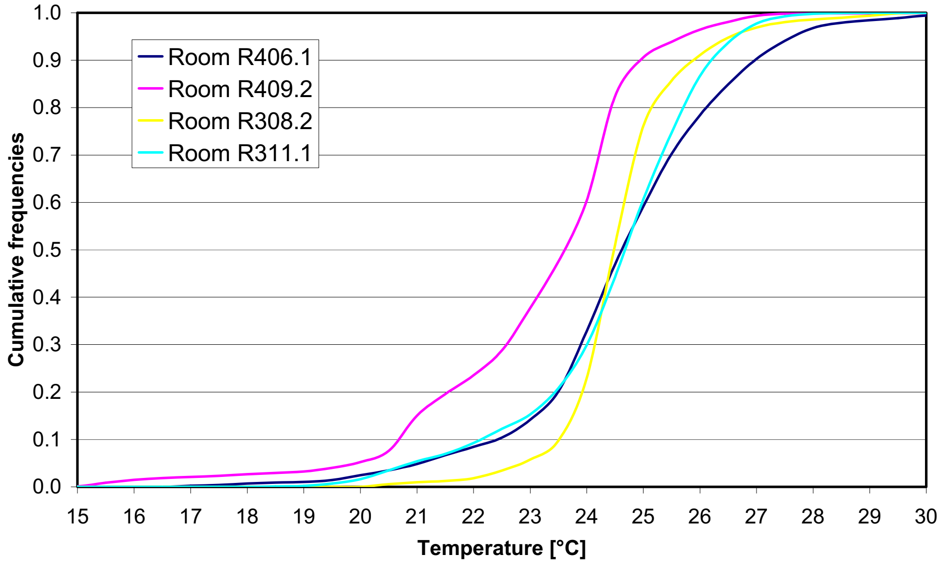


Fig. 41 Cumulative frequencies of temperatures in attic guest rooms

Both cafeterias and kitchens are located in the P building. The cafeteria on the 1st floor (ground floor) serves as a regular restaurant with the opening hours from 11 A.M. to 8 P.M. The location of cafeterias can be seen in Fig. 42 and Fig. 44. A few photos from the inside of the cafeterias can be seen in Fig. 43 and Fig. 45.

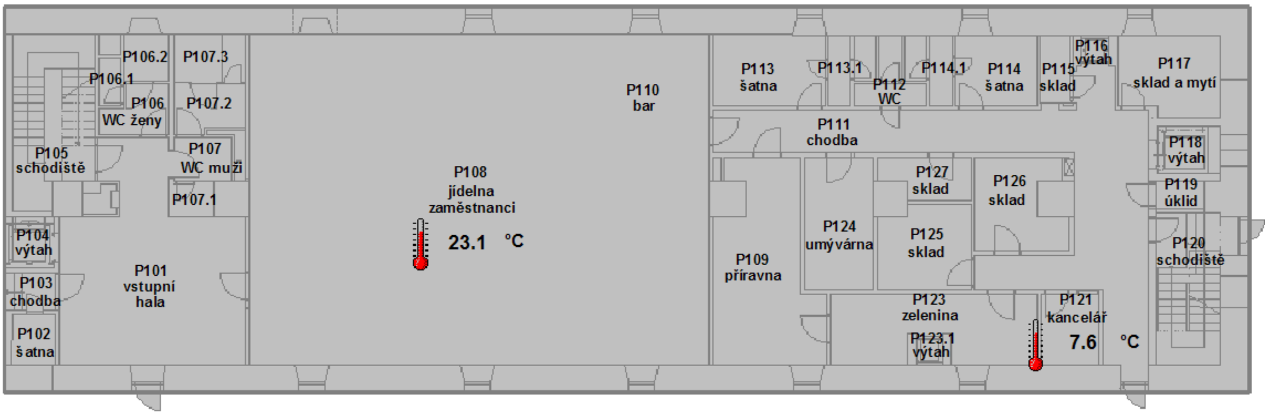


Fig. 42 BMS screen shot of the 1st storey of P building (cafeteria/restaurant is room No. P108)

Fig. 43 Cafeteria P108 (the restaurant)

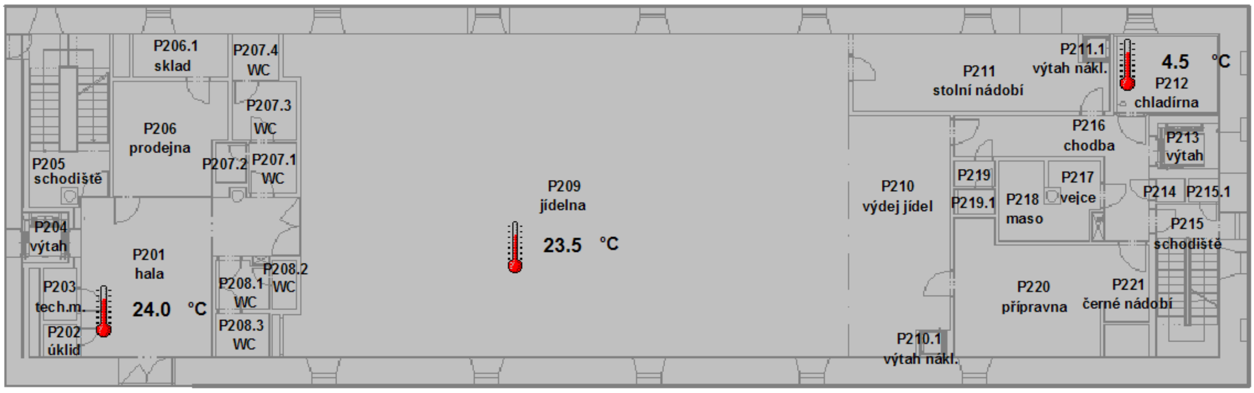


Fig. 44 BMS screen shot of the 2^{nd} storey of the P building (cafeteria is room No. P208)

Fig. 45 Cafeteria P209

The BMS screen shot in Fig. 46 shows the 1^{st} and the 2^{nd} storey of the R building. There are two multi-purpose rooms on the first storey of the R building - the small room (R106) and the large one (R109 plus R110). The bigger room has a bar (R206) in the corner that can be used for receptions and other similar events. Both multi-purpose rooms are currently used by the Faculty of Fine Arts as exhibition rooms. The photos of the multipurpose rooms can be seen in Fig. 47 and Fig. 48. There is an auditorium (R211) and a student club (R212 and 213) on the second storey of the R building. Two photos of the auditorium can be seen in Fig. 49 and two photos of the club in Fig. 50.

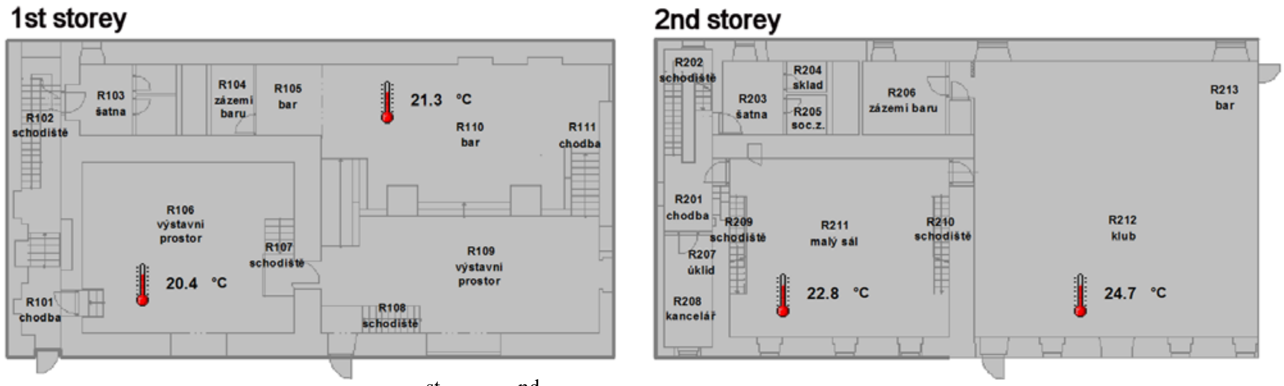


Fig. 46 BMS screen shot of the 1st and 2nd storey of R building

Fig. 47 Small multi-purpose room (R106)

Fig. 48 Large multi-purpose room (R109, R110)

Fig. 49 Auditorium (R211)

Fig. 50 Student club (R212, R213)

The cumulative frequencies of temperatures in the cafeterias, auditorium, club and multipurpose rooms (in the time period from September 1, 2007 to April 30, 2008) are shown in Fig 51.

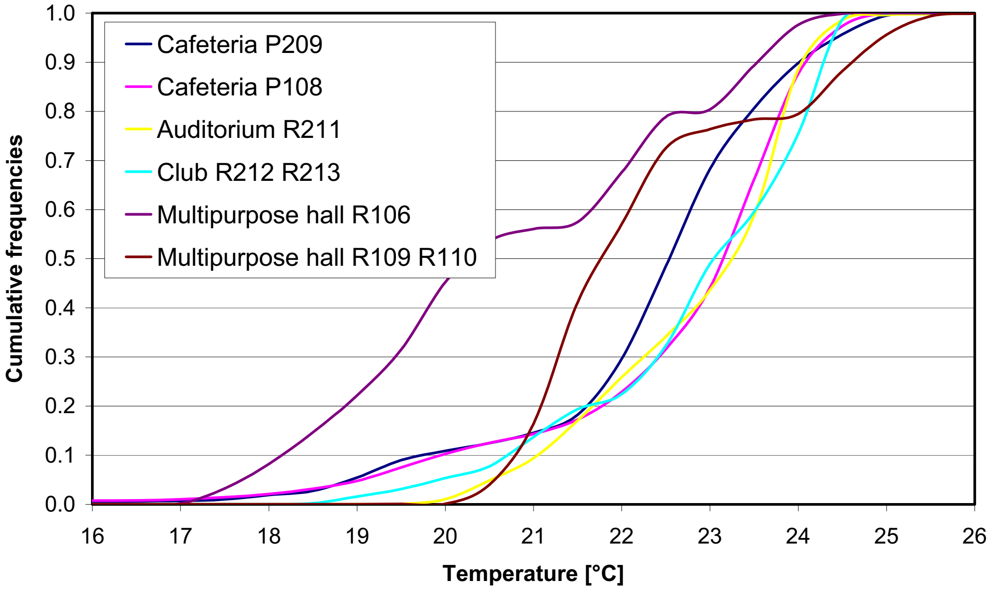


Fig. 51 Cumulative frequencies of temperatures

Air temperature is just one of the parameters influencing the thermal comfort in indoor environments, but the parameter considered the most important by the laymen. It is true that the air temperature is really the most important factor influencing the thermal comfort of occupants if the mean radiant temperature is very similar to air temperature, air velocities are small ($v_a < 0.1$ m.s^{-1}) and relative humidity is within a comfortable range of 30% to 70% (better 40% to 60%).
As can be seen in Fig. 39, Fig. 41 and Fig. 51, the median air temperature in majority of rooms was rather high (mostly above 23 °C) in the time period from September 1, 2007 to April 30, 2008. This is in contrast to the design conditions. The operative temperature of 20°C was considered for thermal loss and heat consumption calculations. Higher indoor air temperatures, of course, results in higher thermal losses and therefore in higher consumption of energy for heating. The high indoor temperatures in the monitoring period offer a potential for further energy savings in future when the users become more aware of their influence on energy consumption

6.8 Summary

This chapter summarizes the results of one-year-monitoring of the Brewery. The differences between the expected and achieved energy savings are explained here.

6.8.1 National benchmarks

Before jumping to the conclusions about the achieved savings it is good to have a look at benchmarks of the energy performance of buildings in the particular country. The benchmark data for the countries participating in the BRITA in PuBs project were part of the Work Package 4. The Czech Republic has adopted the Energy Performance of Building Directive in its legislation and the energy labeling of buildings is in progress. The energy audits and energy labeling help to provide data for the benchmarks. The benchmarks for the university buildings in the Czech Republic are in Table 14.

Table 14 National benchmark for the university buildings

	Heating energy consumption			Electrical energy consumption		
	low	average	high	low	average	high
University buildings	87	173	456	19	60	253

6.8.2 Foreseen and obtained energy savings

The expected and achieved energy savings are presented in Table 15. The floor area of the Brewery increased from 2 300 m^2 to 2660 m^2 during the retrofit (attic space was converted into guest rooms). The energy savings per square meter of floor area for the pre-retrofit floor area are also presented in Table 15 to allow comparison of the predicted and obtained savings under the same conditions.

Table 15 Predicted and obtained energy savings

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, heating and ventilation	165.4	124.4 (143.8)[1]	380 500	330 773

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, electricity	22.4	18.5 (21.4)	51 500	49 118

[1)] *values in parenthesis are for the floor area before retrofit*

As can be seen in Table 15 the obtained savings for the first year of operation are lower than predicted savings for both heat and electricity. The lower than expected savings of heat can be attributed to the high indoor temperatures and high consumption of heat by ventilation. The heat consumed by space heating system was 177 116 kWh/a which is 66.6 kWh/m^2 a (see Table 10). Nevertheless, consumption of energy for heating was reduced by 50% compared with the situation before the retrofit (from 660 000 kWh/a to 329 227 kWh/a). This is a very good result.

A little bit lower than expected savings of electricity were mainly caused by smaller size of the installed photovoltaic system at the Brewery. The project proposal expected that a 33 kWp system would be installed at the Brewery yielding 33 000 kWh/a of electricity. Much smaller system (13 kWp) was finally installed because of the lack of space. The system produced 11 232 kWh during the monitored year. Even though the contribution of the PV was more than 20 000 kWh less than expected in the proposal the savings were less than 2 400 kWh short of the target. It means that other energy saving measures save more electricity than expected.

The total annual consumption of heating energy and electricity for the Brewery was much lower than average consumption of university buildings in the Czech Republic (compare Table 16 and Table 14).

Table 16 Measured energy consumption

Heating energy consumption		Electrical energy consumption	
[kWh/m^2 a]	[kWh/a]	[kWh/m^2 a]	[kWh/a]
123.8	329 227	43.2	114 882

6.8.3 Overall energy consumption evaluation

	Before retrofit	After Retrofit Foreseen	Saved foreseen	After Retrofit Measured	Saved measured
Primary Energy [kWh/m^2 a] - heating energy only	315.7 (floor area 2300 m^2, primary energy factor 1.1)	133.7 (floor area 2300 m^2 primary energy factor 1.1)	182 (floor area 2300 m2 primary energy factor 1.1)	136.2 (floor area 2660 m2 primary energy factor 1.1)	179.5
Primary Energy [kWh/m^2 a] – DHW heating	-	-	-	30.7	-
Primary Energy [kWh/m^2 a] – DHW heating	199.7 (floor area 2300 m^2, primary energy factor 2.8)	137.0 (floor area 2300 m^2, primary energy factor 2.8)	62.7 (floor area 2300 m^2, primary energy factor 2.8)	120.9 (floor area 2660 m^2, primary energy factor 2.8)	78.7

6.8.4 Overall Economic evaluation

Total extra costs (Foreseen) [EUR]	Total extra costs (Observed) [EUR]	Saving (Foreseen) [EUR/a]	Saving (Observed) [EUR/a]	Payback Foreseen [a]	Payback Observed [a]
574,200	925,000	32,227	30,628	20.8	30.2

Energy prices used in calculations:
heat 0.062 EUR/kWh, electricity 0.11 EUR/kWh, PV electricity 0.53 EUR/kWh

6.9 Lessons learned

Design phase proved the saying that “design is not a straight line”. Many changes had to be made in the proposed energy-saving measures.
Lesson learned: Be open-minded and ready for changes.

It is more difficult to design and implement energy-saving measures in case of building retrofits than in case of newly built buildings. Some changes in design may be necessary even when the project enters the application phase. The retrofits of very old buildings are especially tricky because many problems reveal themselves only after the project enters construction phase.
Lesson learned: The design phase is virtually not over until the building is “fully” operational.

Using flooded cellars as a heat reservoir for reversible heat pumps (heating in winter/cooling in summer) looked like a very interesting and innovative idea. The pumping tests, however, revealed that water inflow into the cellars might not be sufficient to provide enough heat for heating. Finally, the central heating plant fitted with condensing delivers heat for the Brewery.

Lesson learned: Do not try to be innovative at all costs. A "traditional" solution that works is much better than an innovative one that does not (and can even have higher "replicability").

Operation of all building systems should be tested in the commissioning phase. This, however, is not a guarantee that all building system will operate properly when the building enters regular operation. If, for example, commissioning takes place in summer, operation of the heating system and its control cannot be tested under its normal operation conditions. Fine-tuning of the control of the building systems may be needed during the first months or even years of the building operation.
Lesson learned: Commissioning means much more than handing over the building to the investor. Good contractors know that very well, therefore, avoid signing a contract with the other ones.

Even very sophisticated algorithms of automatic control cannot prevent the building users from foiling the energy-efficient operation of the building. It is very important to educate the building users. It is very desirable to allow occupants be in charge of the indoor environmental conditions, because the main purpose of the building technologies is to provide a comfortable environment for the building users. Moreover, there is a huge psychological aspect in that – people feel much more comfortable when they know (or at least think) that they have control over the environmental conditions.
Lesson learned: Do not underestimate the importance of educating the building users.

7. Vilnius Gediminas Technical University (VGTU), the Main Building

Author: Saulius Raslanas

7.1. General information

Year of construction: 1971
Year of renovation (start): 2004
Number of storey: 7

Heated volume (m^3)
Cubic contents, volume (m^3) 25710
Gross area (m^2) 8484.20
Living area (m^2) -
Floor area (space) (m^2) 8484.20
Window/glass areas (m^2): 1089

7.1.1. Site

The site of the Main Building of Vilnius Gediminas Technical University (VGTU) is in the suburb. Nearby VGTU there is Vilnius university (VU), also residential buildings and forest (Fig 1.).

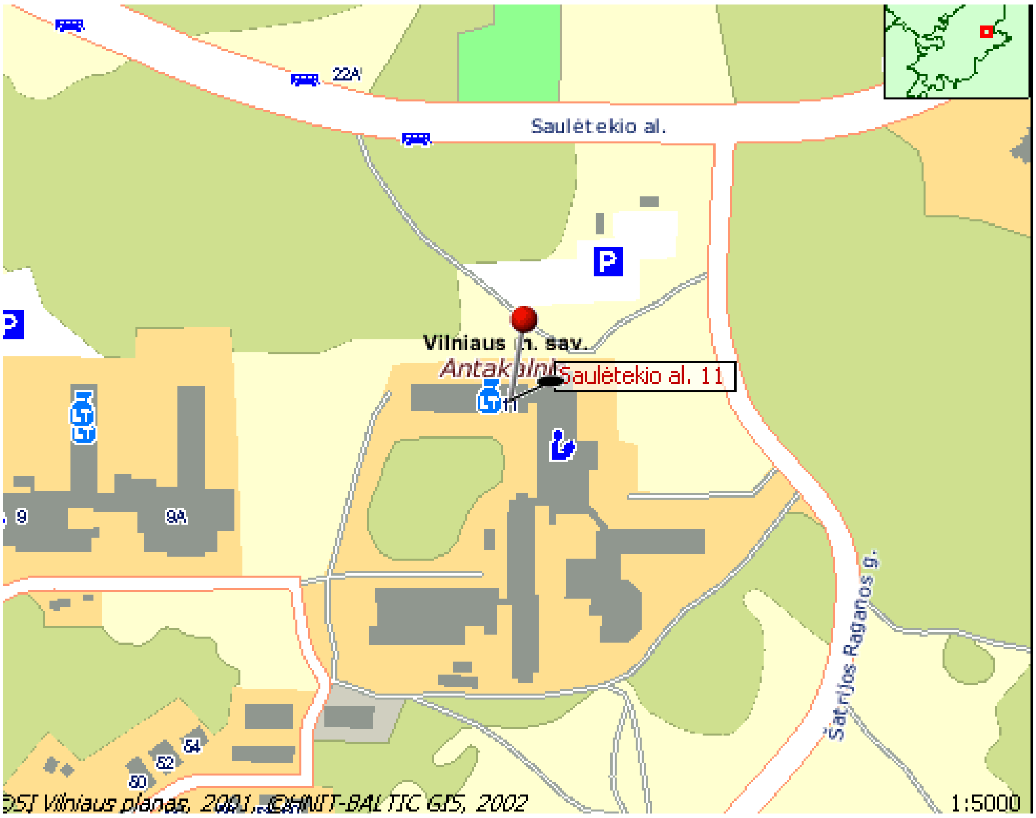


Fig 7.1. Location of the Vilnius Gediminas Technical University (VGTU)

Lithuanian climate is maritime/continental. The highest temperature in July is +30.1°C and the lowest temperature in January is -22.7°C. The Lithuanian climate is temperate. From May to September daytime highs vary from about 14°C to 22°C (57°F to 72°F), but between November and March it rarely gets above 4°C (39°F). July and August, the warmest months, are also wet, with days of persistent showers. May, June and September are more comfortable, while late June can be thundery. Slush under foot is something you have to cope with in autumn, when snow falls then melts, and in spring, when the winter snow thaws. Average annual precipitation 717 millimeters on coast and 490 millimeters in east.

Latitude	54°41’ N.
Longitude	25°17’ E.
Altitude	140-150 m above sea level
Mean annual temperature	6.4°C
Mean winter temperature	-4 °C
Climate description	sunny, temperate

The geographic position of Vilnius (latitude - 54°41’ N., longitude - 25°17’ E., altitude - 140-150 m above sea level) (Fig 2.). The mean annual temperature - 6.4°C, the mean winter temperature -4 °C.

Fig 7.2. Location of the Main Building of Vilnius Gediminas Technical University (VGTU) in Lithuania

7.1.2. Building type

Educational and research

7.2. Before retrofit

7.2.1. Building construction

The main building is public building and the first one that everyone can see after taking the turn-off from Sauletekio Avenue towards Vilnius Gediminas Technical University. The configuration of a rectangular comprises the shape of the building with the measurements 74,30 x 17,22 m. The floor area totals 8484,20 m^2. The main building was built up in 1971. It includes several departments and lecture halls seating from 50 to 100 students (Fig 3.).
Number of storeys – 7.
Number of occupants – 1084,
number of rooms – 219,
average area per user - 7.83 m² .

Address of project	The Main Building of Vilnius Gediminas Technical University Sauletekio al. 11 LT-10223 Vilnius-40 Lithuania
Year of construction	1971
Year of renovation	2004-2006
Total floor area	8484.20 m²
Number of occupants	1084
Number of rooms	219
Typical room	7.83 m²

The substructure of the building is made from frame pillar with columns of UK type. The walls of the building have the ferroconcrete frame and three-layer ferroconcrete panels (60/90/90) (Fig. 3, 4). The thermal transmittance of walls $U_w = 1.07$ *W/m^{2}K.* During thirty years of exploitation, both sun and rainfall have impacted on external sectors partitioned off. Somewhere, connection junctures of three-layer panels are already partly crumbled. Such sealing junctures are easily blowable and pervious to moisture. Juncture in damaged places of the external sectors partitioned off is sealed with warm sealing material and stopped up with a sealant.

Fig 7.3. Photos of the Main Building of Vilnius Gediminas Technical University (VGTU) before retrofit

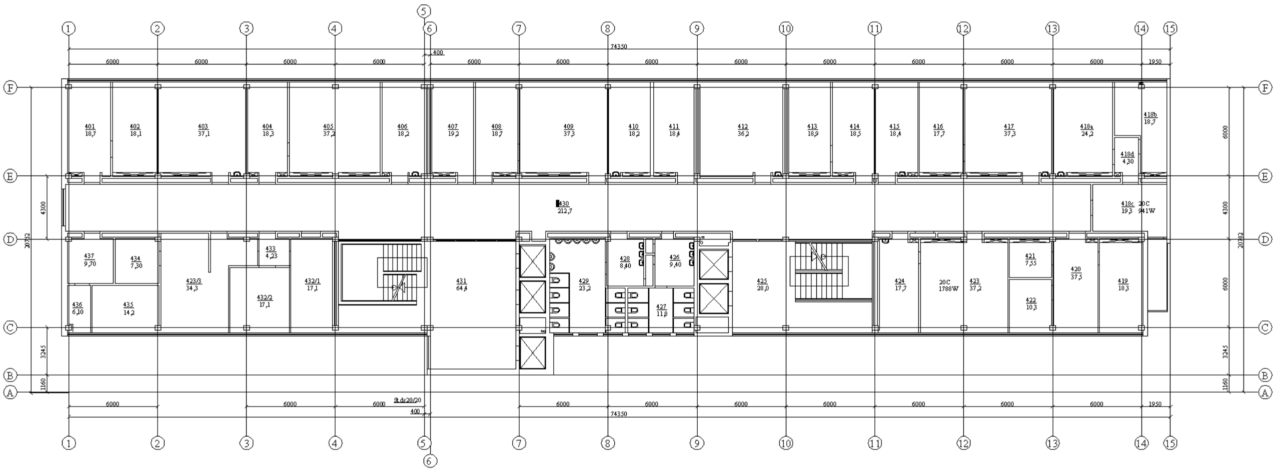


Fig. 4. The plan of 4 th floor the Main building of VGTU

The biggest part of the external sectors partitioned off in the main facades is occupied by glass area. All window glass is placed in wooden or aluminium profile frameworks. The windows of the main building are very old. Closing windows and lack of tightness are the biggest inconveniences. Current construction of the windows does not correspond to the modern window requirements and does not ensure proper inside comfort conditions. The thermal transmittance of existing windows is $U_{wi} = 2.5\ W/m^2K$.

Lateral entrance doors in the Main building are old, unsealed and very insecure as well. The thermal transmittance of doors is $U_d = 2.3\ W/m^2K$.

All roofs of the building are flat, and the covering is made from the roll. In October 2002, the roof of the Main building was repaired. After unwrinkling all blowholes and other roughness of the old covering, new hydroisolating roofing was fit up. While renovating the roof, due to a shortage of financing, current old parapet tins were changed only in these places where they were very rusty. The thermal transmittance of roof is $U_r = 0.8$ *W/m²K.*

7.2.2. Existing heating, ventilation, cooling, lighting systems

Heating system of the Main building VGTU has been working for already thirty years. The heating system is connected to the central heating system according to the independent scheme of connection. Since the Main building VGTU is pretty long, facade regulation of the heating system was carried out in the new thermal unit. Both filiations of heating system were connected to the Central heating system with the help of tabular heating elements, circulating pumps of heating system, and automated regulation of heat quantity as well, which depends on outside temperature. Besides, the regulation of heat quantity may work within diminished temperature work regime in respect of twenty-four hours and days of week. Heating system works according to the diminished temperature schedule from 4 p.m. until 4-5 a.m. as well as on Saturdays and Sundays. With the aim to heat up the main building, the single-pipe heating system of lower distribution is designed and installed. Heating devices are sectional radiators M-140 AO, and convector heaters in lobbies. Mostly heating devices are covered (Fig. 5).

Fig. 7.5. The sectional radiators M-140 AO and convector heaters in lobbies of the Main building of VGTU

In case there is no basement and the ground floor is on the ground, then trunk pipelines are installed in the pathless underground canals. Additionally, in socle floor premises these pipelines are installed openly near the floor (Fig. 6). Therefore, the old and covered heating devices, the old and a little permeable pipelines as well as hardly controlled reinforcement cannot fulfill heating functions of the building even having renovated thermal unit and facade regulation.

Fig. 7.6. The view of pipelines

During heating season, when the windows are not tight, an inside temperature is approximately 14ºC - 16ºC.
Earlier there was an elevator unit. In 2000 VGTU has renovated the unit and instead of it the new automated thermal unit for building needs has been installed (Fig. 7). It prepares the thermal carrier with the help of tubular heat exchangers. In the thermal unit façade regulation of building heating systems is installed. Closing valve, filter, indicator of temperature of initial t_1 temperature and recursive temperature t_2, two thermal transmitters, pumps, expansion vessels and façade indicators are equipped in the thermal unit. Hot water in the Main building is only in several points of hot water as is prepared with the help of electric volumetric thermal transmitters. DHW is prepared with the help of boilers.

Fig. 7.7. View of the thermal unit in the Main building of VGTU

Ventilation system

In the Technical project of VGTU, mechanical air supply/removal systems were foreseen to install in the Main building VGTU. Air paths were installed in particular facilities (between walls) and in the suspended ceiling as well. At the moment, the old mechanical air supply/removal systems are not in use in the Main building because they need a lot of electric power (Fig. 8). Besides, the old systems are too noisy for the building having a particular purpose.

Fig. 7.8. View of the old mechanical air supply/removal systems in not use in the Main building

Illumination and electrical engineering.

When visiting and talking to Computation centre specialists, there were some complains about electrical engineering for computers and other electrical needs of the building are connected from the one point. Especially, it is relevant in cold period of the year when some additional heating devices are being connected and protectors cut out the electric power. In addition, the computers are also disconnected. In all the departments there was a wish expressed to install new lines of electric power supply designed only for computers. The installation for computers should be connected to earth. Additionally, illumination engineering is also out-of-date and does not meet the modern requirements. There are old luminescential illuminators without covering in some offices or auditoriums (Fig. 9).. The level of facilities illumination is insufficient as well.

Fig. 7.9. View of the old luminescential illuminators without covering in the Main building

7.2.3. Energy and water use

	Measured year (2002)	**Total for the whole building**
Space heating	178 kWh/m^2 a	1510188 kWh/a
DHW	* kWh/m^2 a	* kWh/a
Electricity	36,04 kWh/m^{2}a	305737 kWh/a
Water	0,364 m^3/m^{2}a	3088,25 m^3/a

* the DHW data is not available.

7.2.4. User satisfaction before retrofit

Dissatisfaction percentage	Before retrofit
	%
Male occupants	72
Female occupants	85
Total	78,5

Dissatisfaction percentage occupants before and after retrofit of the Main building of VGTU

7.3. Energy saving concept

Recall here what was defined at the design stage

Having in mind that the Main building is in use more than thirty years, it was suggested the following:

- renovation of facades will have a very important impact on energy saving
- replacement of current windows will have a very important impact on energy saving too
- renovation of roof will increase the effect to energy saving
- change of entrance doors will be very important too
- to correct a little bit the operation of renovated thermal unit and complement a part of its automatics, still better effect should be reached.
- Renovation of heating system will increase the effect of energy saving

The efficiency level of the Main building's VGTU refurbishment depends on a great many of factors, including: cost of refurbishment, annual fuel economy after refurbishment, tentative pay-back time, harmfulness to health of the materials used, aesthetics, maintenance properties, functionality, comfort, sound insulation and longevity, etc. Solutions of an alternative character allow for a more rational and realistic assessment of economic, ecological, legislative, climatic, social conditions, traditions and for better satisfaction of architectural, comfort, functional, maintenance and other customer requirements. They also enable one to cut down on refurbishment costs. The developed Multiple Criteria Decision Support System for Building Refurbishment will allow to perform the alternative design of the Main VGTU building's refurbishment, multiple criteria analysis and make the selection of the most efficient versions, etc. The more alternative of refurbishment versions are investigated before making a final decision, the greater are the possibility to achieve a more rational end result. Basing oneself on the collected information and the Multiple Criteria Decision Support System for Building Refurbishment (BRDS) system will be perform a multiple criteria analysis of the VGTU building refurbishment project's components and select the most efficient versions (see http://dss.vtu.lt). After this, the received compatible and rational components of a refurbishment will be joined into the projects. Having performed a multiple criteria analysis of the projects in this way, one can select the most efficient projects.

7.3.1. Building construction

	Pre retrofit Uvalue [w/m^2]	Post retrofit Uvalue [w/m^2]
Walls	1,07	0,296
Roof	0,8	0,2
Windows	2,5	1,16
Doors	2,3	1,5

Energy audit recommended to change all current windows having old construction as well as sectors partitioned off in lobbies. They should be replaced with the new windows or glass surface. The selection of a low-e windows was made by the MCDM method COPRAS and using DSS, developed by authors (see http://dss.vtu.lt) **(see Table 1).**. A new window has to be glazed with 4/16 Ar/4 Kms double glass unit. The thermal transmittance of glass unit U_g = 1,1 W/m^2K, weighed sound reduction index R_w = 33 (-2, -6) dB. A new window is foreseen to fit up with the third opening position or with closing infiltration airhole in order to keep inside microclimate.

Table 1. The data obtained in multiple criteria analysis of five contractors' bids in pre-qualification for window replacement in the Main building of VGTU

PQC	Units of measu-rement	*	Weights of criteria	Ltd 1	Ltd 2	Ltd 3	Ltd 4	Ltd 5
Mechanical strength and stiffness	**	+	0.06875	1	1	1	1	1
Reliability	Cycles	+	0.07275	10000	10000	10000	10000	10000
Thermal transmittance U_p of profile	W/m^2K	–	0.091	1.2	1.4	1.4	1.4	1.4
Thermal transmittance U_g of double glazing unit	W/m^2K	–	0.108	1.1	1.2	1.1	1.1	1.14
Emission ability of low emissive glass coating ε	***	–	0.0575	0.05	0.1	0.05	0.05	0.05
Weighed sound reduction index R_w	dB	+	0.08275	34	33	34	33	32
Air permeability, when pressure difference Δp = 50 Pa	(m^3/m^2h)	–	0.0615	0.18	0.15	0.18	0.3	0.31
Water-tightness	Pa	+	0.0755	600	300	600	250	250
Warranty period	Years	+	0.0755	10	5	5	5	5
Longevity	Years	+	0.07725	35	30	50	40	30
Light transmittance τ_v of double glazing unit	%	+	0.055	81	78	81	79	78
Duration of works	Days	–	0.05625	60	50	60	60	60
The number of windows with two opening positions (horizontal and vertical) (in percent of the total area of windows)	%	+	0.05375	78.5	100	37	100	27.43
The number of windows with closing infiltration air vent or the third opening position (in % of the total area of windows)	%	+	0.0645	78.5	100	37	100	27.43

∗ The sign z_i (+/–) indicates that a higher/lower criterion value satisfies a client

** - Does it meet the specification requirements (if so, =1)

*** - There is no particular unit for criterion measurement.

The windows were selected with the following technical characteristics: thermal transmittance of the profile $U_p = 1.2$ W/m^2K, thermal transmittance of double glazing unit $U_g = 1.1$ W/m^2K, emission ability of low emissive glass coating $\varepsilon = 0.05$, weighed sound reduction index $R_w = 34$ dB, light transmittance of double glazing unit $\tau_v = 81$ %, water-tightness $p = 600$ Pa, warranty period 10 years, longevity 35 years, duration of works – 60 days, the number of windows with the third opening position (in % of the total area of windows) 78.5 % (see Fig 11)..

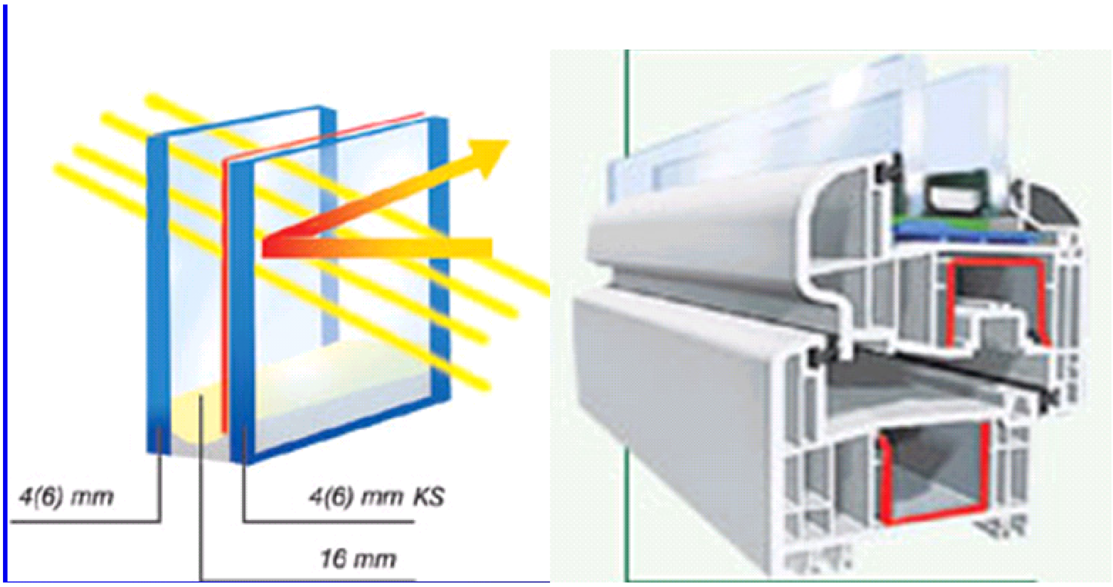


Fig. 7.10. The sketches of new windows glass units and profiles

Before placing thermal insulation on external façade walls, it is necessary to:

1. Clean the old cracked surface of façades until the solid basis is reached and to restore the cracked places.
2. To remove the existing tins of parapets and windowsills.

Stone wool will be used for thermal insulation of walls, and façades will be finished with patterned daub and façade decoration panels. For thermal insulation of the part of façade between the axes „5 – 8“, material of 100 mm will be used (70 mm heating insulation of stone wool ($\rho = 30$ kg/m^3) and 30 mm heating and wind insulation of stone wool ($\rho = 90$ kg/m^3)). Façade decoration panels will be used for finishing (see Fig 12). Z type profiles will be used for insulation fastening; the profiles will be placed every 600 mm (see Fig 13). The remaining part of the façade will be covered with thermal insulation of 130 mm: stone wool ($\rho = 140$ kg/m^3). This part will be daubed with patterned daub, which will be placed on levelling grout with a reinforcement net glued to the heat insulation, and painted with good quality façade painting twice (see Fig 14). 30 mm stone wool ($\rho = 140$ kg/m^3) will be used for heat insulation of window edges. They will be daubed and painted white. Windowsills will be covered by tin with pural covering.

A 100 mm thermal insulation (polystyrene foam rubber EPS 150, M25) will be attached on flashing of the semi-basement using bituminous glue; the insulation will go into the ground by more than 60 cm. Special humidity-resistant semi-basement panels will be attached to the insulation using special profiles. 30 mm stone wool ($\rho = 140$ kg/m^3) will be used for heat insulation of window edges, and semi-basement panels will be used for finishing. Windowsills will be covered by tin with pural covering.

Fig. 7.11. The main façade of renovation

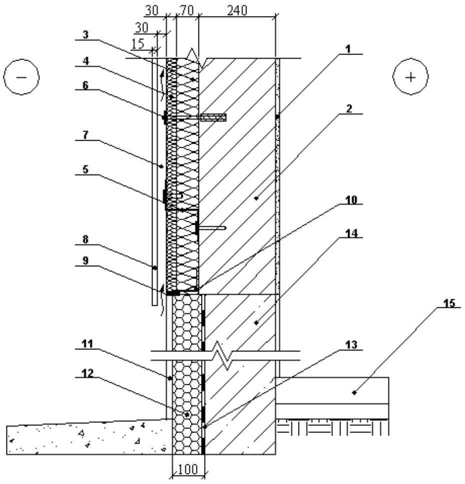


Fig. 7.12. Thermal insulation of walls by using façade decoration panels

1. Internal daub
2. Existing wall
3. Heat insulation: stonewool ($\rho = 140$ kg/m^3)
4. Glue
5. Additional plugs for stonewool fastening with the core from stainless steel
6. Grout for levelling with the reinforcement net
7. Daub
8. Façade decoration panels
9. Band for seam sealing
10. Special profile
11. Special humidity-proof panel for semi-basements
12. Heat insulation for semi-basements; goes into the ground >60 cm (polystyrene foam rubber EPS 150, (M25))
13. Hydro insulation
14. Existing floor
15. Façade decoration panels

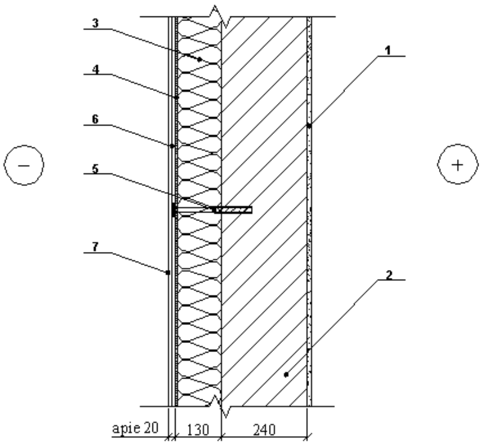


Fig. 7.13. Thermal insulation of walls by using thin daub for finishing

1. Internal daub
2. Existing wall
3. Heat insulation: stonewool ($\rho = 140$ kg/m^3)
4. Glue
5. Additional plugs for stonewool fastening with the core from stainless steel
6. Grout for levelling with the reinforcement net
7. Daub

The area of walls of the central building of VGTU for external thermal insulation by using thin daub for finishing is 2900,4 m^2 and by façade decoration panels 656,2 m^2.
Several different materials are offered for finishing of façades: patterned daub and façade decoration panels. Façades will be daubed with patterned daub and painted with good-quality façade painting (twice). Since existing plastic windows and spaces between windows are white, it is offered to paint façades with several shades of grey: dark grey for the semi-basement, grey for the largest surfaces of the façade and light grey for daubed spaces between windows and external walls of the technical floor. Window edges will be daubed and painted white.
Façade decoration panels are offered for finishing of the projected barrier of metal ventilation shaft and for finishing of lift shafts in the main façade and the foyer (between axes „6-8“). The panels have magnolia colour (matched to the existing natural stone finishing of facades).
Parapets and windowsills of the building will be covered with zinc tin covered with plastic. Windowsills will be white, and parapets will be grey.
The flat roof of the central building of Vilnius Gediminas Technical University in Saulėtekis is being reconstructed by placing additional heat insulation using materials of 120 mm thickness (80 mm semi-hard and 40 mm hard stone wool) and using two layers of new roll roofing (see Fig 15). A slope will be formed using expanded clay layer of 0...150 mm thickness in order to grant good water diversion to funnel. The existing parapet will be heightened to a height of 60 cm. The parapets will be covered by profiled zinc tin with pural; the tin will be attached to the frame made from wooden beams covered with antiseptic, and their external side will be daubed with patterned daub. The old tin of parapets and ventilation shafts will be replaced by new (zinc tin covered with pural). The funnels will also be replaced, and ventilation chimneys will be mounted.

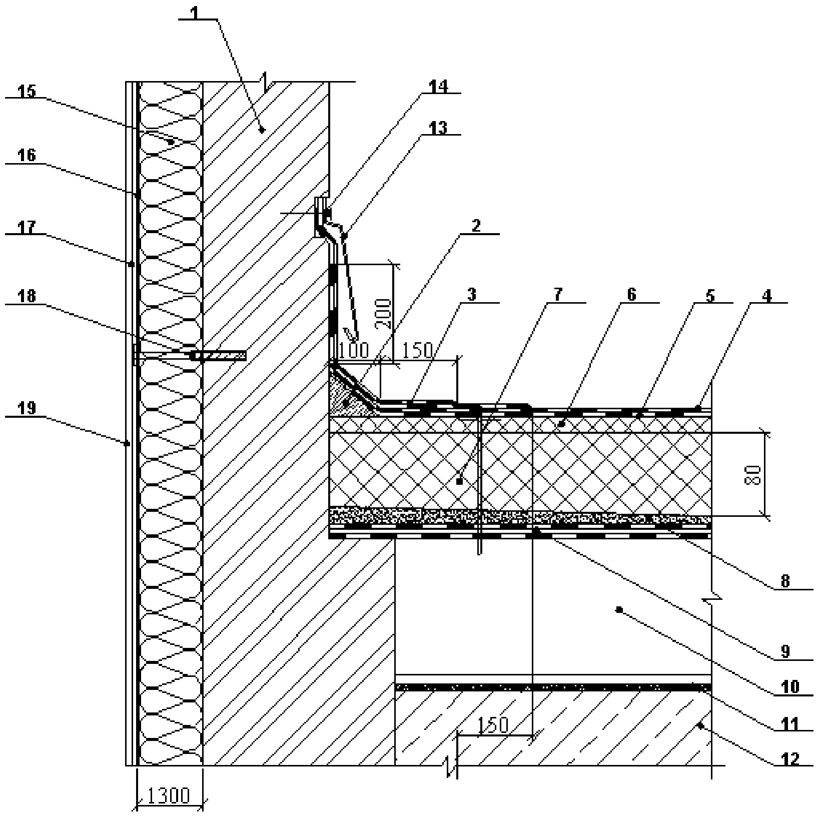


Fig. 7.14. Renovation of roof

1. Existing wall .
2. Wooden side with antiseptic covering
3. Additional two hydro insulation layers
4. Upper hydro insulation layer
5. Lower hydro insulation layer
6. Hard heat insulation (ρ = 160 kg/m^3)
7. Semi-hard heat insulation (ρ = 110 kg/m^3)
8. Layer for slope formation
9. Existing hydro insulation
10. Existing heat insulation
11. Existing vapour insulation
12. Existing supporting ferro-concrete panel
13. Zinc tin covered with pural
14. Nails for brick walls
15. Heat insulation: stonewool (ρ = 140 kg/m^3)
16. Glue
17. Additional plugs for stonewool fastening with the core from stainless steel
18. Grout for levelling with the reinforcement net
19. Daub

7.3.2. Heating

It was suggested to carry out renovation of current morally and physically out-of-date heating system of the main building. It would include three stages of this process:

1. A technical project regarding heating system will foresee new, fully automated heating system, automated compensation valves designed for the stands of the heating systems,

new closing reinforcement, installation of thermostatic valves for heating equipment, change of trunk pipelines and co-ordination of the project as well.
2. Implementation of the heating system renovation according to the technical project.
3. Coordination and operation of the renovated heating system. An act regarding the heat effect.

During the partial renovation of the thermal unit, the electromagnetic indicator “Katra” SKM-1M for heat and water quantity is planning to be installed. With the help of indicator the heat quantity for the Main building VGTU is determined, the quantity of flowing water, instantaneous debit, initial and recursive temperature, initial and final pressure. Data of indicator may be transmitted by internet and the indicator managed by computer programs.

This list of normative documents have been used in designing plants:

1. STR2.05.01:1999 “Heating technology for surfaces of buildings”
2. STR2.09.04:2002 “Power of the heating system in a building. Energy consumption for heating”
3. STR2.09.02:1998 “Heating, ventilation and air conditioning”
4. Instructions for installation of heat insulation on equipment, 2005
5. Instructions for construction of heating supply networks and heating plants, 2005
6. STR2.01.01(6):1999 “Essential requirements for a building. Energy saving and heat preservation”
7. RSN 156-94 “Constructional climatology”

A heating plant is constructed in the Main building of VGTU where reconstruction of the heating system is being performed; the plant receives heat from the central heating system. Separate nodes for façades, i.e. the southern side and the northern side, will be mounted in the heating plant of the central building. A node for ventilation will be installed in this plant as well. Nodes in the heating plant will be mounted according to the new parameters of heating systems.

The heating system will be reconstructed. Systems with bottom distribution will be replaced by two-pipe systems with upper distribution in order to avoid channels under floors. Separate heating systems for the northern façade and the southern façade will be constructed. Baseboard heating systems are designed. Only the hall of the ground floor with windows reaching the floor will have branches going from frames mounted in a channel under the floor.

In the technical floor (7th floor), the systems of frames will be constructed, i.e. distribution from frames to radiators with side connections.

Plastic pipes are used in the baseboard system. Trunk pipes and frames will be made from steel. Distribution to frames is planned near the ceiling of the 6th floor. Closing fittings and balancing valves will be installed in branches leading to frames and also in branches leading to the technical floor. Closing fittings will be installed in the supply line and the return line, and balancing fittings only in the return line.

Fixed supports and compensators will be installed in the main pipelines. The planned compensators are made from steel and have axial expansion for space saving purposes. Frames will also have compensators and fixed supports. However, the pipeline compensation is checked or, to be precise, solved in the work project. T-form fastening plates will be fixed at each heating device in the baseboard system. Also pipelines will be fastened using plastic fastening elements every 0.5 m.

Closing fittings are also planned in the supply line for branches going from frames, and balancing fittings in the return line. The solutions on hiding of the fittings or leaving them in open are presented in the work project.

Trunk pipelines and frames are insulated; the insulation used for frames will be thinner for space saving purposes. Plastic pipes that will be laid in floor constructions will have a protective shell, i.e. this way frames will be moved and laid from other premises to narrower ground floor and the basement.
Steel radiators of various height (mostly of 30 cm) and size will be used as heating devices (see Fig 16). The projected radiators will have legs and bottom connections with T-forms allowing connecting to the baseboard system. All these heating devices will have thermostatic valves of advanced positioning and thermostatic heads. Side connections will be used only in the technical floor and for one unit in the basement. Therefore, additional thermostatic and return flow valves are planned for them. Radiators that will be mounted near windows have legs. Others will be attached to walls. Joints of plastic pipes are pressed, non-demountable and suitable for use in wall or floor constructions under a layer of daub or concrete without preparation of primary shafts in advance. Before mounting, all steel pipes will be cleaned till shining and covered by anticorrosive varnish. Water release taps will be installed in the lowest parts of pipelines, and automatic air releasers in the highest.

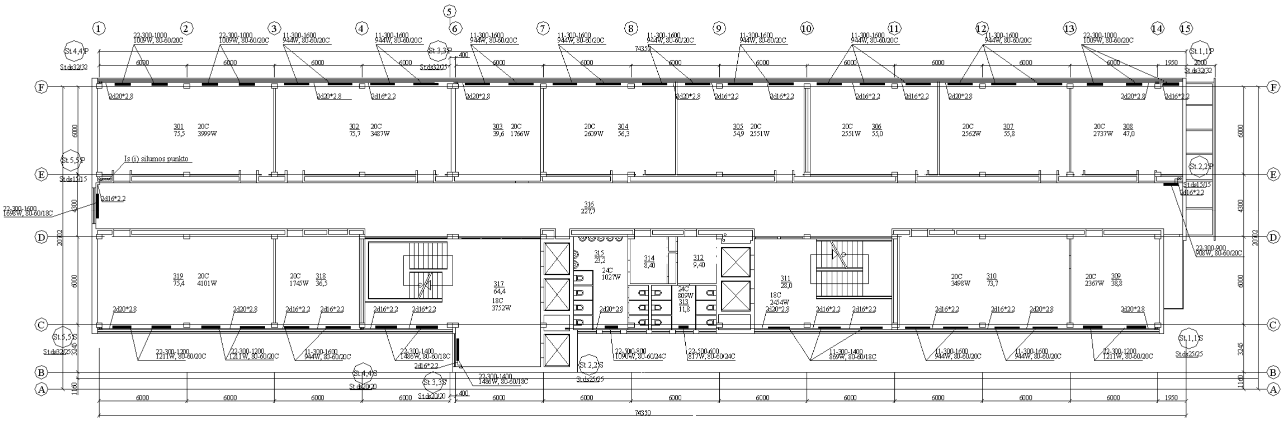


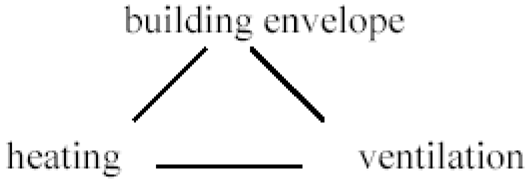
Fig. 7.15. Renovation of heating system (plan of 1st floor the Main building of VGTU)

Temperature parameters of the heating systems: T_{supply} 80ºC, T_{return} 60ºC
Heat demand of the southern heating system: 226 kW (with the coefficient 1.1 according to STR2.09.04:2002).
Heat demand of the northern heating system: 210 kW (with the coefficient 1.1 according to STR2.09.04:2002).
Pressure loss in the southern heating system: 13
Pressure loss in the northern heating system: 12.4
The calculatable outside air temperature: -23ºC.
Heat carrier: water.
Heat loss in the premises was calculated when heated air was supplied to the premises through a mechanical ventilation system.
Pipes for heating ventilation are laid in the channel under floor from a separate ventilation node in the heating plant and divided to two branches near the basement ceiling, i.e. for calorifer nodes of ventilation cameras in the basement and for calorifer nodes of ventilation cameras in the technical floor. Mixing nodes are installed at each calorifer.
Temperature parameters for the heating for ventilation system: T_{supply} 80ºC, T_{return} 60ºC
Heat demand for ventilation: 377 kW.
Pressure loss: 11
Heat carrier: water.
Closing taps and balancing valves will be installed in distribution branches of the main pipelines. Compensators will be installed and fixed supports will be constructed in the

straight sections of the main pipelines; the compensators will be made from steel and will have axial expansion. Steel pipes will be cleaned to metallic shining, covered by anticorrosive covering twice, fastened and insulated.

7.3.3. Ventilation

The original idea of the Main Building renovation of Vilnius Gediminas Technical University (VGTU) was to replace windows, to renovate thermal unit, roof, heating system, to insulate facades and to change entrance doors. These renovation implements (renovation project based on medium investments) for the proposal were written according to the conclusions of audit (performed in 2002). In the process of renovation the balance between the three components must be kept:



Renovation of mechanical air supply/removal systems foresees:

1. A technical project, in which it is suggested to replace current old ventilation system with the new one, fully automated. Ventilation should be mechanical, with 50-70 percent recuperation. In addition, new pipelines of air supply/removal and equipment should be installed.
2. Implementation of air supply/removal systems renovation according to the Technical project.
3. Installation and co-ordination of renovated ventilation systems. Acts regarding installation and co-ordination works of the systems.

Mechanical air supply and removal systems are designed for the main building of VGTU for maintenance of sanitary and hygiene conditions in the premises. Air amounts are calculated according to norms set for the creation of air exchange in the premises and removal of diffused pollutants. On the basis of the General Requirements, the following was planned for the reconstruction of ventilation in the building located in Saulėtekio al:

1. Air supply and removal ventilation with heat retrieval is designed for auditoriums and workrooms.
2. To make the most of the existing special ventilation premises.
3. Management of ventilation systems: from a single location specified for each block and local.
4. Striving to reduce additional repair work: to lay pipelines instead of the existing systems to the possible extent.
5. Systems of blocks must be separate/independent.

THE MAIN VENTILATION INDICATORS

BUILDING NAME	TOTAL AREA, m^2	EXTERNAL TEMPERA-TURE, ºC	HEAT/COLD DEMAND, kW		PLANNED ELECTRIC LOAD
			FOR VENTILATION	COLD DEMAND	
FOR PUBLIC NEEDS	8,484.08	IN WINTER -23 IN SUMMER 26.1	kW *395	-	kW ~ 76*

* note: heat and electric loads are corrected after selection of supplier’s aggregates.

EXPLANATORY NOTE

While preparing the ventilation section in the project for the central building of Vilnius Gediminas Technical University in Saulėtekio al. 11, Vilnius, the following material was used:

- Heating, ventilation and air-conditioning “Regulation on Technical Requirements for Construction”; STR 2.09.02.1998; STR 2.09.02.2005;
- Hygiene norm. Acoustic noise HN 33-2001;
- Fire safety. Main requirements. RSN 133-91;
- Hygiene norm. Marginal values for concentrations of harmful chemical substances in the air of work premises. General requirements. HN 23-2001;
- Hygiene norm. Heat comfort and sufficient thermal environment in work premises.
- Limited values of parameters and measurement requirements. HN 69-1997;
- Hygiene norm. Microclimate in residential and public buildings. HN 42:1999;
- STR 2.05.01:2005 Thermal equipment for walls, roofs and floors of buildings.
- Hygiene norm. Institutions of vocational training. HN 102:2001

In order to maintain sanitary and hygiene conditions, mechanical air supply and removal systems are designed for premises. Air amounts were calculated for the determined norms to form air exchange in premises and to remove pollutants.
Positions of ventilation systems and air amounts are designed in order to form negative pressure in WC premises, to avoid distribution of unpleasant odours to work rooms. Optimal conditions for air exchange are created.
On the basis of Appendix 3 (A. General requirements), the following was planned for the ventilation section in the reconstruction of the building in Saulėtekio al.:
Ventilation for air supply and removal with heat recovery for classrooms and offices will be designed. Systems for classrooms and offices will be separate where possible.
Maximal use of the existing ventilation chambers.
Operation of ventilation systems: from a single specified place for each block and local.
In order to reduce additional repair works, pipelines will be laid in the place of the existing to the possible extent.

Systems for each block must be separate/independent.

- in work rooms: 3.6 m^3/h for 1 m^2 (no visitors);
- in work rooms: 5.4 m^3/h for 1 m^2 (open for visitors);
- in conference rooms: 14.4 m^3/h for 1 m^2;
- in classrooms: 10,8 m^3/h for 1 m^2;

- WC: exhaustion of 108 m^3/h per one toilet bowl/urinal and of 75 m^3/h per one shower;
- utility premises: exhaustion of 7.2 m^3/h for 1 m^2 ;
- air exchange once an hour is planned in the halls;
- canteen: 18 m^3/h for 1 m^2;
- ventilation in the kitchen according to the existing technology;
- library and reading-room: 7.2 m^3/h for 1 m^2;
- storeroom and auxiliary premises without work places: 1.3 m^3/h for 1 m^2;
- one time exchange is planned in the ventilation chambers.

Amounts of the supplied and removed air are specified on a separate sheet “Technical characteristics of ventilation systems“.

LIST OF NORMATIVE DOCUMENTS USED FOR THE PREPARATION OF THE PROJECT

1. STR 1.01.06:2002. Specific buildings.
2. STR 1.01.07:2002. Simple buildings (temporary among them).
3. STR 1.01.08:2002. Construction type of a building.
4. STR 1.01.09:2003. Classification of buildings according to their purpose.
5. STR 1.04.01:2002. Research of the existing buildings.
6. STR 1.05.06:2005. Designing of a building.
7. STR 1.14.01:1999. Calculation of area and volume.
8. STR 2.01.01 (1): 1999. Essential requirements for buildings. Mechanical permanence and durability.
9. STR 2.01.01 (2): 1999. Essential requirements for buildings. Fire safety.
10. STR 2.01.01. (3): 1999. Essential requirements for buildings. Hygiene, health and environment protection.
11. STR 2.01.01. (4): 1999. Essential requirements for buildings. Use safety.
12. STR 2.01.01. (5): 1999. Essential requirements for buildings. Noise protection.
13. STR 2.01.01 (6): 1999. Essential requirements for buildings. Energy saving and heat retention.
14. STR 2.01.03:2003. Declared and projected thermal technical values of construction materials and goods.
15. STR 2.01.04:2004. Fire safety. Main requirements.
16. STR 2.02.02:2004. Public buildings.
17. STR 2.05.01:1999. Thermal equipment for walls, roofs and floors of buildings.
18. STR 2.05.02:2001. Buildings’ constructions. Roofs.
19. STR 2.05.03:2003. Introduction to designing of building constructions.
20. STR 2.05.04:2003. Effects and loads.
21. STR 2.05.05:2005. Designing of concrete and ferro-concrete constructions.
22. STR 2.05.07:2005. Designing of wooden constructions.
23. STR 2.05.09:2005. Designing of brick constructions.
24. STR 2.09.01 :1998. Heat supply networks and heating stations.
25. STR 2.09.02:1998. Heating, ventilation and air conditioning.
26. RSN 156-94. Constructional climatology.
27. HN 69:2003. Heat comfort and sufficient thermal environment in work premises.
28. RPST-01-97. State fire safety regulations. Main requirements.
29. HN 33-1:2003. Acoustic noise. Allowed levels in residential and work premises.

30. RSN 134-92. Public buildings. Fire protection requirements.
31. BPST 01-97. General fire protection regulations.
32. RSN 138-92*. Fire protection automation in buildings.
33. HN 42:2004. Microclimate in residential and public buildings.
34. RSN 99-87. Instructions for covering of wood with anti-septic and increasing of fireproof qualities.

The air exchange scheme

Aggregates of the systems TI-1, TI-2, TI-3 and TI-4 are planned in the technical floor of the building, in the former ventilation compartment where the existing old equipment will be already dismantled and the premises cleaned. Aggregates of the above-mentioned systems are mounted on a floor insulated with *AKUSTO* or other sound absorbing plates. The systems TI-1 and TI-2 serve auditoriums in the 6th and 5th floors. It is planned to mount air-ducts in the existing shafts between the corridor and auditoriums. Only those parts that hinder construction of new air-ducts leading to the premises are dismantled in shafts of the building. Aggregates of the systems TI-3 and TI-4 serve workrooms in 6th, 5th, 4th and 3rd floors. Air-ducts of these systems are installed in a vertical shaft designed along axes A-F/15 of the building. Air-ducts installed in a brick shaft are insulated with stone-wool and aluminium foil of 100 mm, also fixed with adhesive tape and metal holders. Air-ducts are fixed to the wall of the building. In order to avoid noise, noise silencers are planned together with ventilation aggregates of 2,000 mm in length. The systems TI-3 and TI-4 are considerably big; therefore, it is possible to install noise silencers in each floor additionally. Air is removed through the roof by air-ducts protruding at 1 m and by installed elbows with a net. Air is supplied using metal grid with regulators. Air is supplied using diffusers in the corridors where hanging ceilings are planned.

It is planned to mount the systems TI-5, TI-6, TI-7, TI-8, TI-9, TI-10 and TI-11 in the former ventilation compartments in the basement. Old equipment is dismantled, premises cleaned and painted. Air collection grid through a wall is installed for the air supply, and the air from systems TI-5 and TI-6 is removed through a former air collection shaft where the grid is replaced. The system TI-6 serves the hall in the ground floor and rooms in the basement. Since it is not allowed to connect to old channels without inspection (they may be dirty, cracked and leaky), it was decided to lift air-ducts to the ground floor through rooms and then „hide” them in the walls. High capacity air releasers of type CS500 are planned for air ventilation in the hall. The system TI-5 serves rooms in the 1st floor. The system TI-7 serves premises in the 2nd floor, mainly auditoriums. The system TI-8 serves auditoriums in the 1st floor. The system TI-9 serves auditoriums in the 2nd floor. The system TI-10 serves the library and the reading hall located in the ground floor.

TECHNICAL CHARACTERISTICS OF VENTILATION SYSTEMS

SYSTEM MARKING	NO. OF SYSTEMS	SERVICED PREMISES	FILTER	VENTILATOR			ELECTRIC ENGINE			AIR HEATER/ COOLER				NOTES
				TYPE	AIR AMOUNT L, m^3/h	PRESSURE P, Pa	POWER N, kW	REV NUMBER N/min	EMITTED NOISE LEVEL dB	TYPE	AIR TEMPERATURE		HEAT AMOUNT, kW	
											FROM	TO		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T1 I1	1 1	CLASSROOMS, 5th & 6th FLOORS	EU5 EU3	Centrifugal Centrifugal	4,052 4,052	350 350	3 3	1,700 1,700	60	water	-23	+18	30	Rotary recuperator
T2 I2	1 1	CLASSROOMS, 5th & 6th FLOORS	EU5 EU3	Centrifugal Centrifugal	2,668 2,668	350 350	1.7 1.7	1,900 1,900	59	water	-23	+18	16	Rotary recuperator
T3 I3	1 1	OFFICES, 5th & 6th FLOORS	EU5 EU3	Centrifugal Centrifugal	6,623 6,229	680 700	3 3	1,600 1,600	52	water	-23	+18	50	Rotary recuperator
T4 I4	1 1	OFFICES, 3rd &4th FLOORS	EU5 EU3	Centrifugal Centrifugal	9,386 8,504	800 800	6 6	1,425 1425	60	water	-23	+18	70	Rotary recuperator
T5 I5	1 1	OFFICES, 1st FLOOR	EU5 EU3	Centrifugal Centrifugal	2,088 1,647	350 350	1.8 1.5	1,850 1,850	29	water	-23	+18	18	Rotary recuperator
T6 I6	1 1	PREMISES IN THE BASEMENT AND THE GROUND FLOOR	EU5 EU3	Centrifugal Centrifugal	3,285 2,916	350 350	2.6 1.9	1,200 1,200	42	water	-23	+18	46	Rotary recuperator
T7 I7	1 1	CLASSROOMS AND OFFICES, 2nd FLOOR	EU5 EU3	Centrifugal Centrifugal	5,476 4,975	550 550	3.5 3.1	2,400 2,400	29	water	-23	+18	45	Rotary recuperator
T8 I8	1 1	CLASSROOMS, 1st FLOOR	EU5 EU3	Centrifugal Centrifugal	5,538 5,538	700 700	3 3	1,475 1,475	30	water	-23	+18	46	Rotary recuperator
T9 I9	1 1	CLASSROOMS, 2nd FLOOR	EU5 EU3	Centrifugal Centrifugal	3,106 3,106	550 550	2.3 2.3	1,900 1,900	55	water	-23	+18	30	Rotary recuperator
T10 I10	1 1	LIBRARY AND READING-ROOMS, GROUND FLOOR	EU5 EU3	Centrifugal Centrifugal	634 634	200 200	0.5 0.5	1,900 1,900	54	water	-23	+18	4	Rotary recuperator

TECHNICAL CHARACTERISTICS OF VENTILATION SYSTEMS

SYSTEM MARKING	NO. OF SYSTEMS	SERVICED PREMISES	FILTER	VENTILATOR			ELECTRIC ENGINE			AIR HEATER/ COOLER				
				TYPE	AIR AMOUNT L, m^3/h	PRESSURE P, Pa	POWER N, kW	REV NUMBER N/min	EMITTED NOISE LEVEL dB	TYPE	AIR TEMPERATURE		HEAT AMOUNT, kW	NOTES
											FROM	TO		
1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
T11 I11	1 1	CANTEEN, GROUND FLOOR	EU5 EU3	Centrifugal Centrifugal	4,381 2,560	350 400	3 2.2	2,730 1,800	49	water	-23	+18	40	Plate recuperator
I12	1	WC, GROUND, 1^{ST} & 2^{ND} FLOORS	-	Centrifugal.	3,564	400	2.5	2,400	44					In insulated casing or on the roof
I13	1	WC, 3rd, 4th, 5^{th} and 6th FLOORS	-	Centrifugal.	4,752	450	3.5	2,800	52					In insulated casing or on the roof
I14	1	WC, 3rd, 4th, 5th and 6th FLOORS	-	Centrifugal.	3,888	400	2.5	2,400	48					In insulated casing or on the roof
I15	1	WC GROUND, 1^{ST} & 2^{ND} FLOORS	-	Centrifugal.	2,916	400	2.5	2,400	42					In insulated casing or on the roof
I16	1	FROM THE KITCHEN HOOD WITH FAT FILTERS	-	Centrifugal.	2,000	500	2.5	1,850	47					Special fat-resistant with Teflon vanes

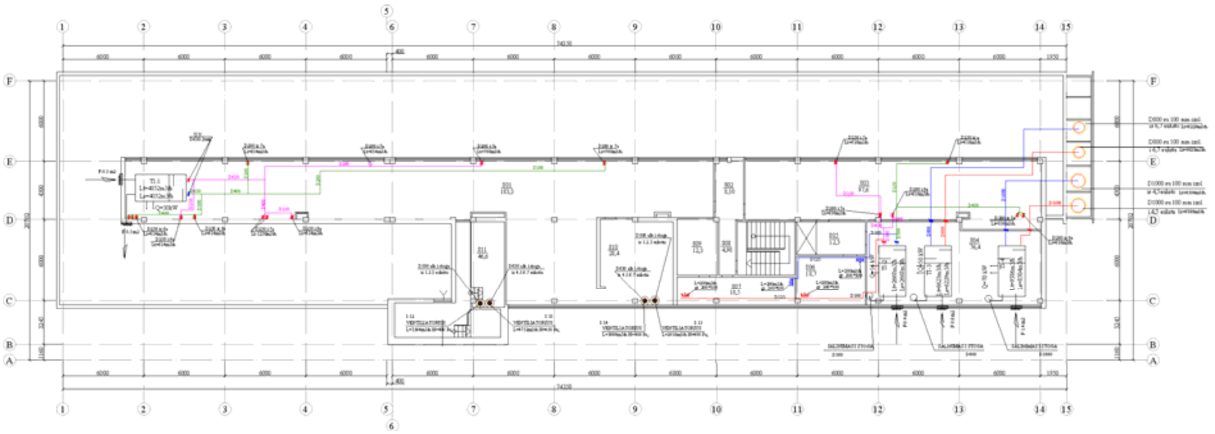


Fig. 7.16. Renovation of ventilation system (plan of technical **floor** the Main building of VGTU)

Patalpos Nr.	Patalpos pavadinimas	Patalpos plotas, m2
801	Ventiliatorinë	183,3
802	Koridorius	8,10
803	Ventiliatorinë	97,6
804	Ventiliatorine	76,4
805	Koridorius	12,3
806	Dailininko kabinetas	18,7
807	Dailininko kabinetas	18,5
808	Koridorius	4,98
809	Pagalbinë patalpa	12,3
810	Krovininio lifto patalpa	28,4
811	Keleivinio lifto patalpa	46,6

The air from the systems TI-7, TI-8, TI-9 and TI-10 is removed to the joint air-duct, which goes through a brick shaft to a wall without windows. A reverse valve is installed on air-ducts of each system. The air of the above-mentioned systems is collected 2 m above the ground and removed through a wall without windows. Air-ducts in the shaft are insulated with a layer of stone-wool of 100 mm (thickness) and also fixed with the adhesive tape and metal holders. Ventilators are planned in the technical floor for WC ventilation. The systems I-12 and I-15 remove air from ground, 1st and 2nd floors, and the systems I-13 and I-14 remove air from 3rd, 4th, 5th and 6th floors. Two systems are planned for each floor. Since the amount of the removed air is quite large, it is planned to supply 1/3 of aspirated air amount to the wash-hand premises due to possible large overpressure in WCs. Then the aspiration will be more effective and doors will open easily. Metal regulated diffusers aspirate the air. The ventilator has a protection against overheating. The highest noise emitted to the environment is 47-52 dBA.

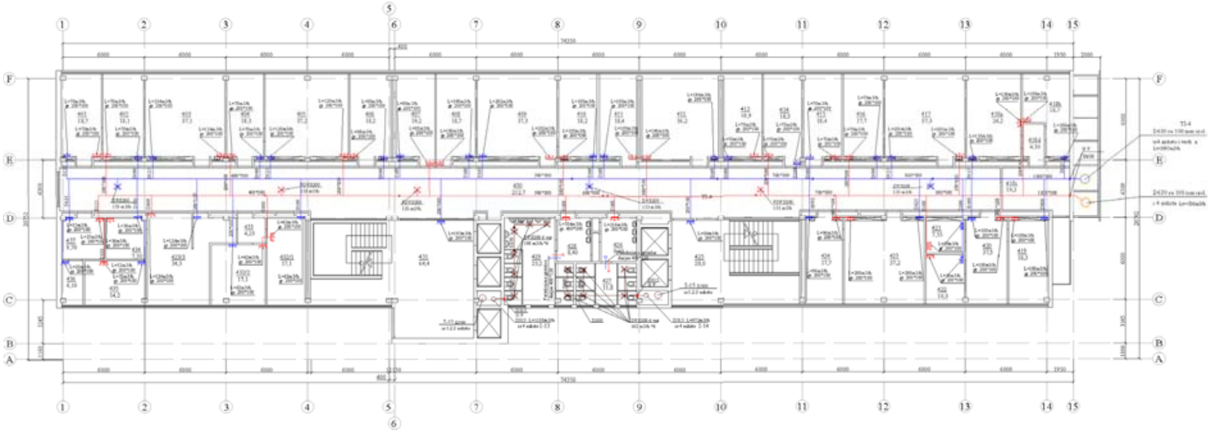


Fig. 7.17. Renovation of ventilation system (plan of 4 st the Main building of VGTU)

Patalpos Nr.	Patalpos pavadinimas	Patalpos plotas, m2
401	Buhalterës pavaduotojos kabinetas	18,7
402	Vyr. buhalterës kabinetas	18,1
403	Ekonomikos direkcija	37,1
404	Reikalø tvarkytojos kabinetas	18,3
405	Ûkio direktoriaus kabinetas	37,2
406	Pastatø eksploatacijos valdyba	18,2
407	Pastatø eksploatavimo valdyba	19,2
408		18,7
409	Statybos technologijø ir vadybos katedra	37,3
410	Statybos technologijø ir vadybos katedra	18,2
411	Statybos technologijø ir vadybos katedra	18,4
412	Spec. lëðø buhalterija	36,2
413	Ekonomikos direkcija	18,9
414	Ekonomikos direkcija	18,5
415	"Inþinerijos" redaktoriaus kabinetas	18,4
416	Statybos fakulteto prodekano kabinetas	17,7
417	Statybos fakulteto metodinis kabinetas	37,3
418a	Statybos technologijø ir vadybos katedra	24,2
418b	Statybos technologijø ir vadybos katedra	18,7
418c	Statybos technologijø ir vadybos katedra	19,3
418d	Koridorius	4,30
419	Statybos fakulteto prodekano kabinetas	18,3
420	Statybos fakulteto prodekano kabinetas	37,5
421	Statybos fakulteto prodekano kabinetas	7,55
422	Statybos fakulteto prodekano kabinetas	10,3
423	Statybos fakulteto dekano kabinetas	37,2
424	Statybos fakulteto dekanatas	17,7
425	Laiptinë	28,0
426	Prausykla	9,40
427	San. mazgas	11,8
428	Prausykla	8,40
429	San. mazgas	23,2
430	Koridorius	212,7
431	Fojë	64,4
432/1	Buhalterija	17,1
432/2	Buhalterija	17,1
432/3	Buhalterija	34,3
433	Koridorius	4,23
434	Kasa	7,30
435	Buhalterija	14,2
436	Buhalterija	6,10
437	Buhalterija	9,70

Aggregates for air supply/aspiration are with rotary recuperators, except TI-11. TI-11 is provided with a plate recuperator. All compartments consist of: filters (EU 5 and EU 3 class), ventilators, water heating calorifers, terminator and automation. Thermal capacity is planned with a reserve; VGTU at the request could install aggregates with a plate recuperator. All air-ducts in ventilation compartments and going through floors and in shafts are insulated with a heat insulation of 100 mm (thickness). The forecasted air movement speed in the premises is 0.2 m/s.

7.3.4. Predicted energy savings

Energy saving measures, heating, cooling, ventilation	[kWh/m^{2}a]	Total [kWh/a]
high-efficient windows	26	220589
insulation of roofs and facades	27,9	236672
heating system	36	305663
Ventilation system (heating recovery system)	42,2	297000
Total heating energy savings	**132,1**	**1059924**

7.3.5. Predicted costs and payback

Energy saving measure/investment	Area [m²]	Total costs [EUR]	Saving [EUR/a]	Pay-back periods [a]
Insulation of facades	2425	105.349	8.166	12,9
Windows	1000	109.696	8.295	13,2
Roof	1306	17.020	633	26,88
Change of entrance door	25	6.154	145	42,4
Renovation of the thermal unit		2.298	1.354	1,7
Heating system	8484.20	185.026	11.364	16,2
Ventilation system		467.587 (eligible 42.606)	11.028	42,4
Total		**893.130**	**40.985**	**21,8**

Energy costs used for the payback calculation:
Thermal : 36,14 €/MWh.
Electric: 85,15 €/MWh

7.4. Life Cycle Assessment

7.4.1. Brief description of the retrofit action:

The actions involved mainly the substitution of old wall insulations with a new and a better performing envelopes, and the installation of high efficiency windows with selective glasses and low thermal transmittance.

Primary energy saving and emissions			
Primary energy save (E_{year})	19 848 845.0		[kWh]
Global Emission saving (EM_{S-i})	4 069.9		[$ton_{CO2\ eq.}$]

Summary of materials employed and main components		
Component		
Roll roofing layers (bitumen)	12.6	[ton]
Expanded polystyrene	8.6	[ton]
Expanded clay	27.7	[ton]
Stone wool	4.2	[ton]
Panel (glued laminated timber)	5.2	[m^3]
Panel (particle board, cement bonded)	3.9	[m^3]
Patterned daub (base plaster)	110.2	[ton]
Wood board	1.7	[ton]
Profiles (steel)	1.0	[ton]
PVC framed windows	1 001.2	[m^2]
Aluminium framed windows	257.1	[m^2]

Energy and Environmental Indexes		
Global Energy Requirements (GER)	1 215 899.0	[kWh]
Global Warming Potential (GWP)	217.32	[ton $CO_{2\text{-Eq.}}$]
Nutrification Potential (NP)	111.07	[kg PO_4]
Acidification Potential (AP)	1 253.18	[kg SO_2]
Ozone Depletion Potential (ODP)	0.16	[kg CFC_{11}]
Photochemical Ozone Creation Potential (POCP)	150.8	[kg C_2H_4]

Synthesis Indexes		
Energy Payback Time ($E_{\text{-PT}}$)	2.0	[year]
Emission Payback Time ($EM_{\text{-PT}}$)	1.9	[year]
Energy Return Ratio (E_R)	16.3	

7.5. Construction phase description

7.5.1. Building construction

1.1.5.1. Windows

The windows in VGTU have been replaced. Total cost of windows replacement is 103542,33 €. Alternative windows of 5 companies according to 16 indicators were analyzed:

- Price
- Mechanical strength and stiffness
- Reliability
- Thermal transmittance Up of profile
- Thermal transmittance Uw of double glazing unit

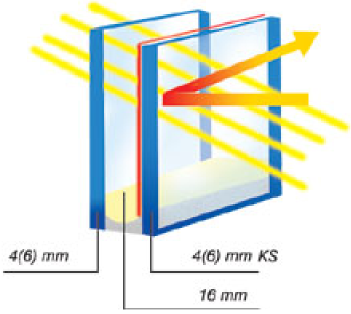
- Emission ability of low emissive glass coating ε
- Parameter *Rw* of air sound isolation
- Air leakage, when pressure difference *Dp* = 50 Pa
- Waterproof-ness
- Guarantee period
- Longevity
- Light transmission of double glazing unit
- Pay-back period
- Duration of works
- Quantity of windows with two opening positions (horizontal and vertical) (in percent of the area of all windows)
- Quantity of windows with closing infiltration air vent or the third opening position (in percent of the area of all windows)

Finally we have selected the windows with the following characteristics:

1. Glass units with energy saving glass Low-E (low-emissive) glass

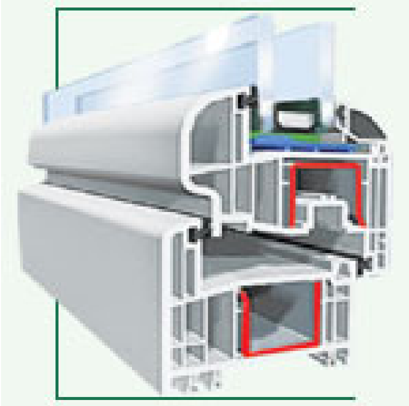
**Uw =1.1 W/sq.mK *Rw<=36 dB*

Selective glass is produced by coating Float glass with metal oxides in the electromagnetic way. The coat of metal oxides (KS) saves heat. This glass has a special surface coating to reduce heat transfer back through the window. These coatings reflect from 40% to 70% of the heat that is normally transmitted through clear glass, while allowing the full amount of light to pass through. Low-E glass with harmless argon gas added offers a 20% improvement over regular insulating glass in reducing heat transmission. This means added comfort and energy savings with this type of glass units. Also almost two-thirds less harmful ultraviolet rays what protects the furniture and drapes from fading.



2. Profile system GEALAN S 8000 IQ

double sealing system, width of profile - **74 mm, 6 chambers,** Thermal transmittance Up **= 1.4 W/sqm °K**



The lateral doors of VGTU main building have been changed.

1.1.5.2. *Insulation*

We have renovated the roof in 2005. The flat roof of the central building of Vilnius Gediminas Technical University in Saulėtekis has been renovated by placing additional thermal insulation using Expanded Polystyrene EPS 150 100 mm thickness and using two layers of new roll roofing (see Fig. 15). A slope was formed using expanded clay layer of 0...150 mm thickness in order to grant good water diversion to funnel. The existing parapet was heightened to 600 mm. The parapets will be covered by profiled zinc tin with pural; the tin will be attached to the frame made from wooden beams covered with antiseptic, and their external side will be daubed with patterned daub. The old tin of parapets and ventilation shafts will be replaced by new (zinc tin covered with pural). The funnels have been replaced.

We have had a problem with roof renovation, because the requirements for thermal insulation changed.

Standard values for thermal transmittance of building's envelops UN, W/(m^2·K) and for thermal transmittance ΨN , W/(m·K) of linear thermal bridges

Envelope	Mark	Residential buildings	Non-residential buildings	
			Public	Industry
Roof	r	UN =0.16·κ	UN =0.20·κ	UN =0.25·κ
Floors, bounded with outside	ce			
Envelops of heating rooms, bounded with ground	fg	UN =0.25·κ	UN =0.30·κ	UN =0.40·κ
Floors above cool cellars	cc			
Walls	w	UN =0.20·κ	UN =0.25·κ	UN =0.30·κ
Windows	wd	UN =1.6·κ	UN =1.6·κ	UN =1.9·κ
Doors	d	UN =1.6·κ	UN =1.6·κ	UN =1.9·κ
Linear thermal bridges	t	ΨN = 0.18·κ	ΨN = 0.20·κ	ΨN =0.25·κ

According to benchmarking with thermal insulation of public buildings, the thermal transmittance of roof U_r is equal:

$$U_N=0.20\cdot\kappa ,$$

where $\kappa = 20/(\theta_i - \theta_e)$ – correction of temperature, θ_i – indoor temperature, ^{o}C; θ_e – mean outdoor temperature for heating season. The permitted value was 0.40·κ, and considering this value we had to insulate roof additionally using expanded polystyrene EPS 150 130 mm thickness**.** In October 2002, the roof of the main building was repaired. After unwrinkling all blowholes and other roughness of the old covering, new hydro-insulation was fit up: two layers of new roll roofing. While renovating the roof, due to lack of funds, the existing old parapet tins were changed only in places where they were very rusty. Considering this situation, it was proposed to the *Brita in Pubs* project to complete the renovation of the roof. It is necessary to open the old roofing near the existing funnels to the ceiling panel and clean them up. Additionally, the roofing around funnels should be sealed and the water gathering function of funnels ensured. In case of necessity, the capping of the old funnel must be replaced. The old parapet tin must be replaced and fastened to the roof parapet construction. The planned cost of roof renovation made up only 17,020 €; however, since the requirements for thermal insulation have been changed, the incurred cost of roof renovation made up 60,000 €.

The walls of semi-basement were renovated by the end of 2005. A 100 mm thermal insulation (expanded polystyrene EPS 150) has been attached on flashing of the semi-basement using bituminous glue; the insulation reaches into the ground by more than 600 mm. Special humidity-resistant semi-basement panels have been attached to the insulation using special profiles. 30 mm stone wool (ρ = 140 kg/m^3) will be used for heat insulation of window edges, and semi-basement panels will be used for finishing. Windows ills will be covered by tin with pural covering.

The walls of the main building of VGTU have been renovated in 2006. One part of the building will be renovated thermally insulating the walls by using façade decoration panels, other part – thermally insulating the walls by using thin daub for finishing. The total area of walls of the VGTU central building which will be externally thermally insulated using thin daub for finishing is 2,900.4 m^2 and the area which will be covered by façade decoration panels is 656.2 m^2.

Several different materials are offered for finishing of façades: patterned daub and façade decoration panels. Façades will be daubed with patterned daub and painted with good-quality façade painting (twice). Since existing plastic windows and spaces between windows are white, it is offered to paint façades with several shades of grey: dark grey for the semi-basement, grey for the largest surfaces of the façade and light grey for daubed spaces between windows and external walls of the technical floor. Window edges will be daubed and painted white.

Façade decoration panels are offered to finish the projected barrier of metal ventilation shaft and to finish lift shafts in the main façade and the foyer (between axes “6-8”). The panels are of colour magnolia (matched to the existing natural stone finishing of façades).

The project was modified during VGTU renovation because of energy saving measures. Due to financial shortages, the third renovation component, i.e. ventilation, lacked attention and therefore it was not planned to refurbish the ventilation system. Since 42,605.61 € have been saved in replacement of windows, it was suggested to use the money for building’s ventilation. According to the project, the following renovation works in the ventilation system are planned: replacement of the old ventilation system with a new, fully automated system with 50-70% recuperation. The renovation of the ventilation system of the VGTU main building commenced at the end of 2006: the foundation, the room and the steel framework for vertical ventilation shafts were constructed.

7.5.2. Heading

7.5.2. Heating

Out of all measures only the renovation of the heating system of the building has not been essentially started. Although, in the very beginning of the renovation, after replacement of window, the convectors in the corridors have been replaced; however, these works were not stated in the financial accounts (see Fig. 7.5.1.).

7.5.1. Fig. The new convectors in the corridors

The renovation of the heating system in terms of money covers about 40 % of all means, necessary for the renovation of VGTU Main building. 35% of EU financing for the already implemented renovation works according to the project has started to receive only at the end of 2007. Moreover, the interior renovation of VGTU Main building has been recently implemented, the walls have been painted, tiles of the walls and the floor have been replaced (see Fig. 7.5.2.) and with regard to this, the renovation of the heating system will damage the decoration. Therefore, these are the reasons that stopped the finishing of the renovation works.

7.5.2. Fig. The Main building of VGTU after interior renovation

In 2000 VGTU has renovated the elevator unit and instead of it the new automated thermal unit for building needs has been installed (see Fig. 7.5.3.). It prepares the thermal carrier with the help of tubular thermal transmitter. During the renovation of the thermal unit the electromagnetic indicator “Katra” SKM-1M for heat and water quantity has been installed (see Fig. 7.5.4.).. With the help of indicator the heat quantity for the Main building is determined, the quantity of flowing water, instantaneous debit, initial and recursive temperature, initial and final pressure. Data of indicator may be transmitted by internet and the indicator managed by computer programmes.

7.5.3. Fig. View of the thermal unit in the Main building of VGTU

7.5.4. Fig. The thermal unit the electromagnetic indicator “Katra” SKM-1M

7.5.3. Ventilation

The design of ventilation foresaw vertical ventilation shafts in the exterior of the main building on the right lateral façade. Air-ducts of these systems are installed in a vertical shaft designed along axes A-F/15 of the building.

Preparing the proposals for separate energy saving means of VGTU demonstration project we have calculated the simple pay-back period (P) as an approximate indicator of economic evaluation. Simple pay-back period of investment is determined as a number of years, during which the savings in project would cover initial investment. When the annual saving during the project remains the same, the simple pay-back period was calculated in the following way:

$$P = \frac{I}{S}$$

where

I – investments, Lt;

S- annual savings, Lt.

The pay-backs for the proposal of ventilation Modifications in the Demonstration Project were written according to the conclusions of audit (performed in 2002). Calculating the simple pay-back period at this time the energy tariff 128,38 LT/MWh 37,18 €/MWh was applied. Since then the energy prices in Vilnius not increased, but even slightly decreased, i.e. 2005 06 29 it was equal 124,8 LT/MWh 36,14 €/MWh. Although air supply/removal systems are partially remained, they are morally obsolescence, they do not satisfy the requirements, the installed equipments require huge energy consumption and it is not advisable to use the system in the future. Therefore while performing project of building heating systems it has been decided to implement complexly a project for ventilation part (with 50-70% air recuperation). The main purpose of ventilation is to improve the air quality in the main building of Vilnius Gediminas technical university, especially in the auditoriums where many students gather. As the recuperation system will be installed, the heating system will be effectively used (there will be no need to open windows during heating season). Currently the detailed ventilation project has been developed, according to which installation of ventilation for the main building would cost even more, because the ventilation shafts should be additionally installed in the outside of building and the old system can not be applied. Current estimated value of ventilation system is 1854056,40 Lt (536972 €), according to the energy audit it was 1 618 050 Lt (468620 €). Taking into account these factors the simple pay-back period would increase more than it was presented in Modifications in the Demonstration Project, i.e. it would be equal 48,69 years. Evaluating the factor that announcing a tender for installation of ventilation the price would be smaller, the simple pay-back period would decrease.

7.6. Monitoring

7.6.1. Monitoring plan

The plan of monitoring consisted from measurements of internal microclimate parameters in rooms (see Fig. 7.6.1.), energy and water consumption, of monitoring performed using a thermavisor, of the level of pollution in the environs of VGTU. The measurements were fulfilled in 2006-2008.

The fourth floor

Fig. 7.6.1. The rooms of the Main building of VGTU, where monitoring has been carried out.

VGTU technical direction, office for building maintenance and commissioning operate and maintain the VGTU Main building. They have an operation and maintenance book. Inputs of heat, electricity and water are recorded every day.

Monitoring is performed using a thermavisor *Therma CAMB2* to assess the quality of insulation and to make thermal pictures of the surface of building’s envelope for calculation of thermal transmittance (see Fig. 7.6.2).

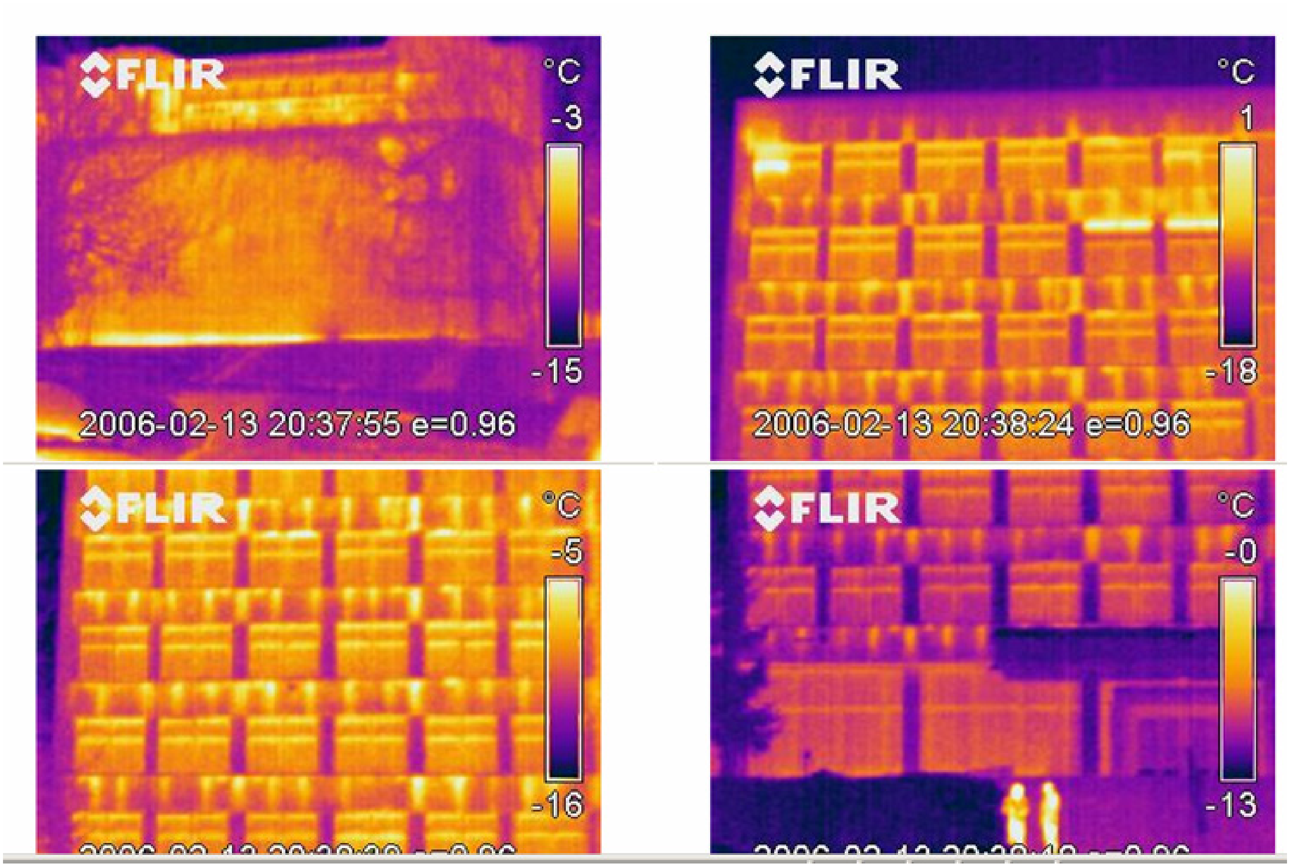


Fig.7.6.2. The thermal pictures of the surface of the Main building's envelope

7.7. Data analysis

7.7.1. Local Weather

Heating period	2001-2002	2002-2003	2003-2004	2004-2005	2005-2006	2006-2007	2007-2008
Start of heating period	22-Oct	22-Oct	13-Oct	13-Oct	17-Oct	23-Oct	15-Oct
End of heating period	15-Apr	21-Apr	17-Apr	11-Apr	20-Apr	27-March	15-Apr
Duration of heating period in days	175	181	187	180	185	155	183
Average external air temperature of heating period; C°	-0,3	-2,1	-0,3	-0,4	-2,1	-0,0933	1,35
Day-degrees of heating period; DD	3203	3638	3422	3312	3719	2776	3047

7.7.2. Energy consumption

Electricity

In 2007 electricity consumption increased by about 18 % compared to 2002 (see Fig. 7.7.1.).

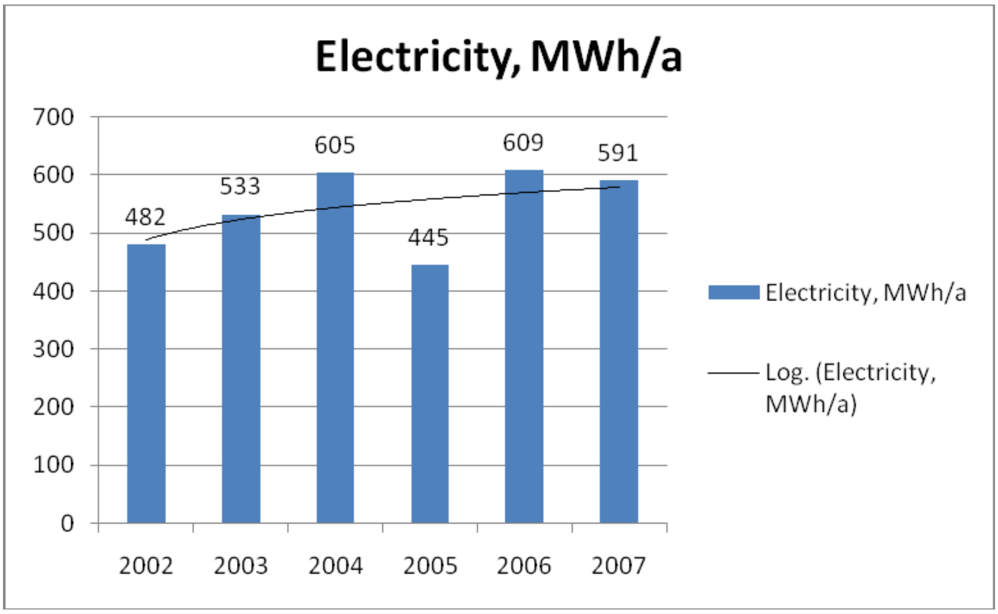


Fig. 7.7.1. A electricity consumption of the Main building of VGTU.

	[kWh/m^{2}a]	Total annual (kWh)
Total electricity	69,66	591000
Primary Energy (Total electricity)	90,56	768312

Thermal

It was possible to compare the data on energy consumption before the renovation and during the renovation. In summer of 2004, the windows of the Main building were replaced. In autumn of 2005, the roof and walls of the semi-basement were insulated and in 2006 – the walls of the Main building of VGTU. In heating season 2002/2003, the energy consumption was 1023 MWh, and in 2006/2007 already 334 MWh. Heating energy consumption decreased significantly, particularly more that by factor 2 (see Fig. 7.7.3.).

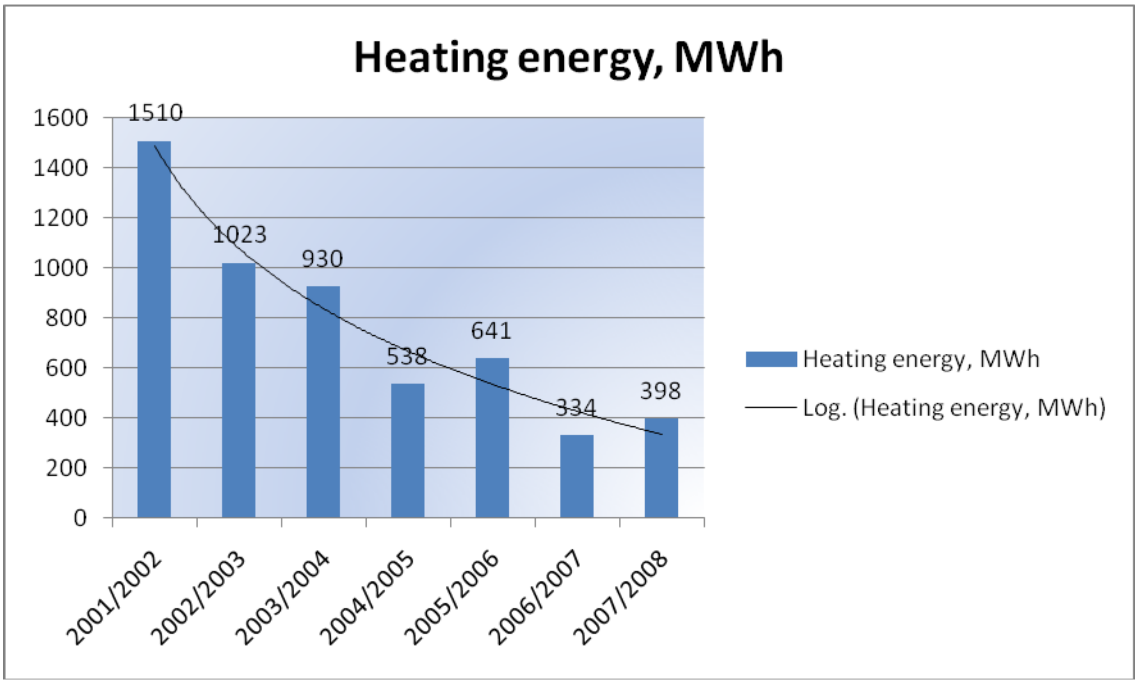


Fig. 7.7.3. A heating energy consumption of the Main building of VGTU.

	[kWh/m^{2}a]	Total annual (kWh)
Total incoming heating energy	46,91	398000
Primary Energy (Total thermal)	72,81	617696

An actual heating energy consumption for normative period was calculated. In heating season 2001/2002 (before renovation), the actual energy consumption was 1888 MWh (see Fig. 7.7.4.). In heating seasons 2002/2003 and 2003/2004 (before renovation), the energy consumption was 1126 MWh and 1088 MWh respectively. The average energy consumption of heating seasons 2002/2003 and 2003/2004 was 1107 MWh. In summer of 2004, the windows of the Main building VGTU were replaced. The energy consumption was 650 MWh in heating season 2004/2005 after replacement of windows (obtained energy saving 457 MWh, predicted after replacement of windows 221 MWh). In autumn of 2005, the roof and walls of the semi-basement were insulated. The energy consumption was 690 MWh in heating season 2005/2006. In summer of 2006, the walls of the Main building of VGTU were insulated. The energy consumption was 482 MWh in heating season 2006/2007 (obtained energy saving 625 MWh, predicted 1060 MWh). Actual heating energy consumption for normative period to compare to the average energy consumption of heating seasons 2002/2003 and 2003/2004 decreased significantly (56%), particularly by factor 2,30. The energy consumption was 523 MWh in heating season 2007/2008 (heating energy saving (52,7%).
The actual heating energy consumption for normative period was calculated for 7 heating periods.

2001-2002

	Actual indicators	Standard indicators
Start of heating period	22-Oct	20-Sep
End of heating period	15-Apr	3-May
Duration of heating period in days	175	225
Average external air temperature of heating period; C°	-0,3	0,20
Average internal premises temperature of heating period; C°	18	18
Day-degrees of heating period; DD	3203	4005
Coefficient of actual heating consumption for normative period	1,25	

Total amount of consumed heating energy during heating period; MWh	1510,19	1887,74
Total amount of consumed heating energy during heating period per 1 sq.m. of heated area; kWh	178,00	222,50

2002-2003

	Actual indicators	Standard indicators
Start of heating period	22-Oct	20-Sep
End of heating period	21-Apr	3-May
Duration of heating period in days	181	225
Average external air temperature of heating period; C°	-2,1	0,20
Average internal premises temperature of heating period; C°	18	18
Day-degrees of heating period; DD	3638	4005
Coefficient of actual heating consumption for normative period	1,101	

Total amount of consumed heating energy during heating period; MWh	1023,00	1126,32
Total amount of consumed heating energy during heating period per 1 sq.m. of heated area; kWh	120,58	132,75

2003-2004

	Actual indicators	Standard indicators
Start of heating period	13-Oct	20-Sep
End of heating period	17-Apr	3-May
Duration of heating period in days	187	225
Average external air temperature of heating period; C°	-0,3	0,20
Average internal premises temperature of heating period; C°	18	18
Day-degrees of heating period; DD	3422	4005
Coefficient of actual heating consumption for normative period	1,17	

Total amount of consumed heating energy during heating period; MWh	930	1088,10
Total amount of consumed heating energy during heating period per 1 sq.m. of heated area; kWh	109,61	128,25

2004-2005

	Actual indicators	Standard indicators
Start of heating period	13-Oct	20-Sep
End of heating period	11-Apr	3-May
Duration of heating period in days	180	225
Average external air temperature of heating period; C°	-0,4	0,20
Average internal premises temperature of heating period; C°	18	18
Day-degrees of heating period; DD	3312	4005
Coefficient of actual heating consumption for normative period	1,209	

Total amount of consumed heating energy during heating period; MWh	538	650,44
Total amount of consumed heating energy during heating period per 1 sq.m. of heated area; kWh	63,41	76,67

2005-2006

	Actual indicators	Standard indicators
Start of heating period	17-Oct	20-Sep
End of heating period	20-Apr	3-May
Duration of heating period in days	185	225
Average external air temperature of heating period; C°	-2,1	0,20
Average internal premises temperature of heating period; C°	18	18
Day-degrees of heating period; DD	3719	4005
Coefficient of actual heating consumption for normative period	1,077	

Total amount of consumed heating energy during heating period; MWh	641	690,36
Total amount of consumed heating energy during heating period per 1 sq.m. of heated area; kWh	75,55	81,37

2006-2007

	Actual indicators	Standard indicators
Start of heating period	23-Oct	20-Sep
End of heating period	27-March	3-May
Duration of heating period in days	155	225
Average external air temperature of heating period; C°	-0,0933	0,20
Average internal premises temperature of heating period; C°	18	18
Day-degrees of heating period; DD	2776	4005
Coefficient of actual heating consumption for normative period	1,443	

Total amount of consumed heating energy during heating period; MWh	334,00	481,96
Total amount of consumed heating energy during heating period per 1 sq.m. of heated area; kWh	39,36	56,80

2007-2008

	Actual indicators	Standard indicators
Start of heating period	15-Oct	20-Sep
End of heating period	15-Apr	3-May
Duration of heating period in days	183	225
Average external air temperature of heating period; C°	1,35	0,20
Average internal premises temperature of heating period; C°	18	18
Day-degrees of heating period; DD	3047	4005
Coefficient of actual heating consumption for normative period	1,314	

Total amount of consumed heating energy during heating period; MWh	398,00	522,97
Total amount of consumed heating energy during heating period per 1 sq.m. of heated area; kWh	46,91	61,64

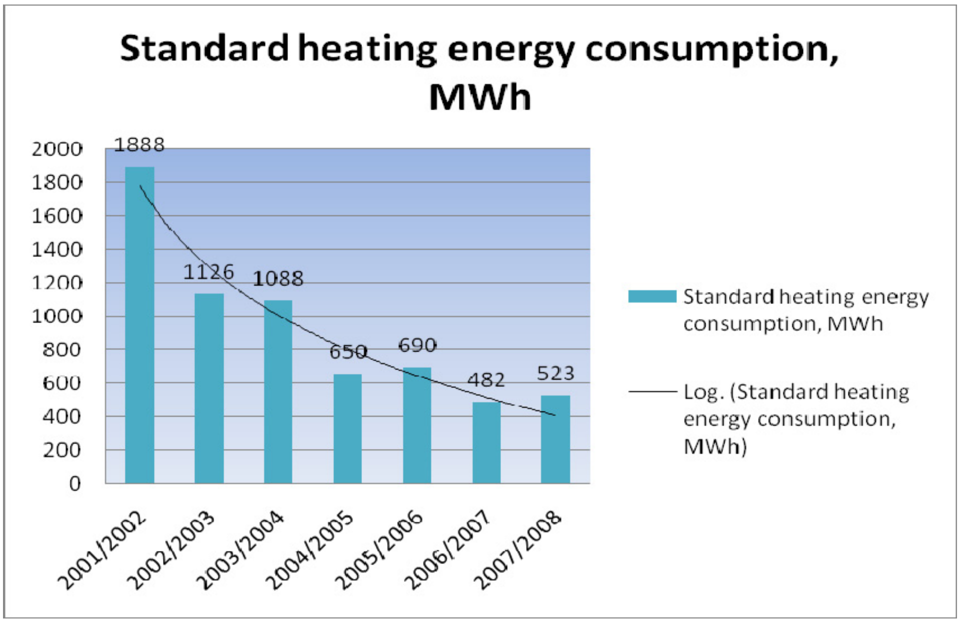


Fig. 7.7.4. A standard heating energy consumption of the Main building of VGTU.

		Total for the whole building
Space heating	61,64 kWh/m^2 a	522970 kWh/a
DHW	n.a. kWh/m^2 a	n.a. kWh/a
Electricity	69,66 kWh/m^{2}a	591000 kWh/a

	(kWh/a)	(kWh/m2 a)
Primary Heating	811630	95.7
Primary Electricity	875271	90.6
Total Primary	1686901	186.2

Water consumption

In 2007 water consumption increased by about 31 % compared to 2003 (see Fig. 7.7.5.).

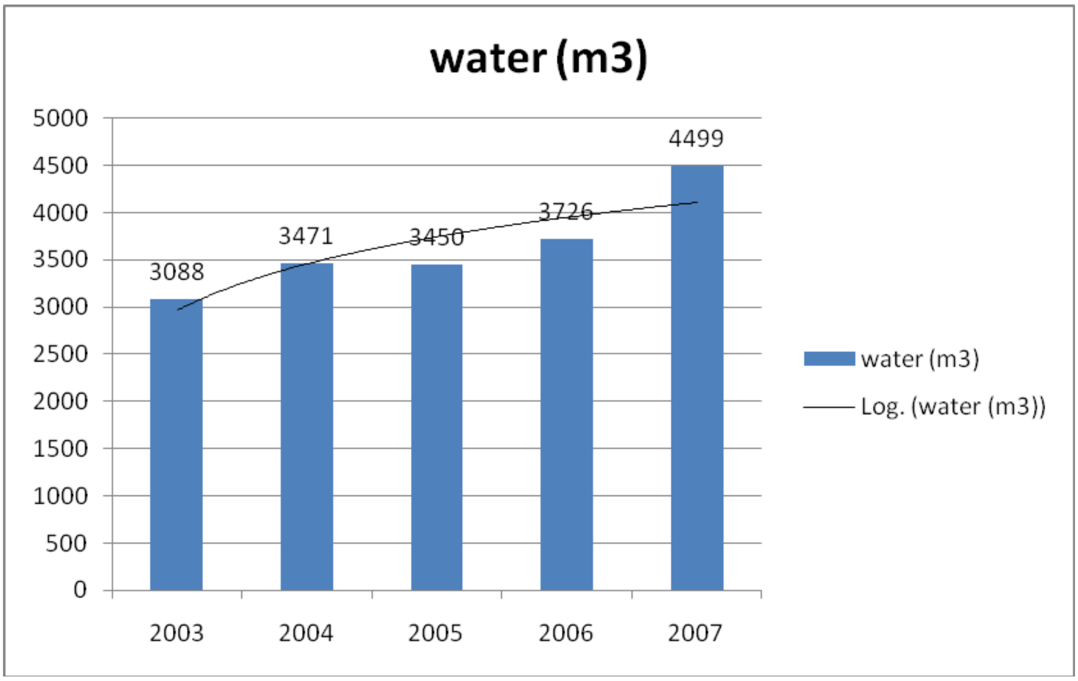


Fig. 7.7.5. Water consumption of the Main building of VGTU.

		Total for the whole building
Water	0,53 m^3/m^{2}a	4499 m^3/a

The level of pollution was measured in the environs of VGTU in 2006-2007: noise pollution (dB), CO pollution (ppm), particular mates pollution (mg/m^3) (see Fig. 7.7.5. and 7.7.6.). A forecast of pollution (noise pollution, dB; CO pollution, ppm) in the environs of VGTU for the year 2010 is provided.

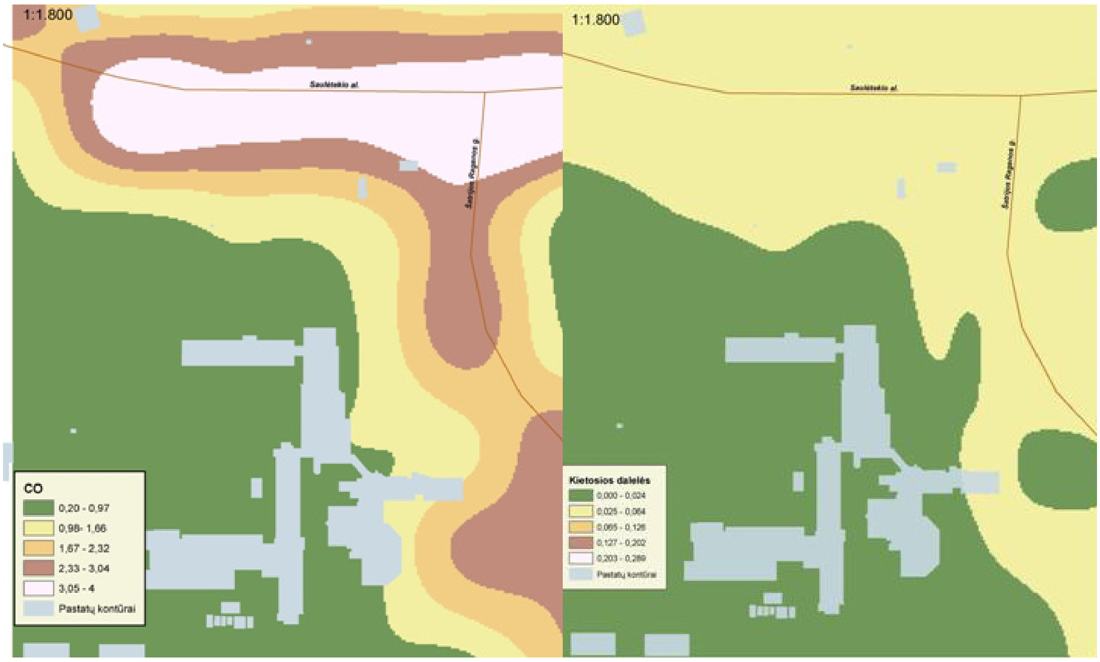


Fig. 7.7.6. Carbon monoxide and particular mates pollution maps in VGTU area

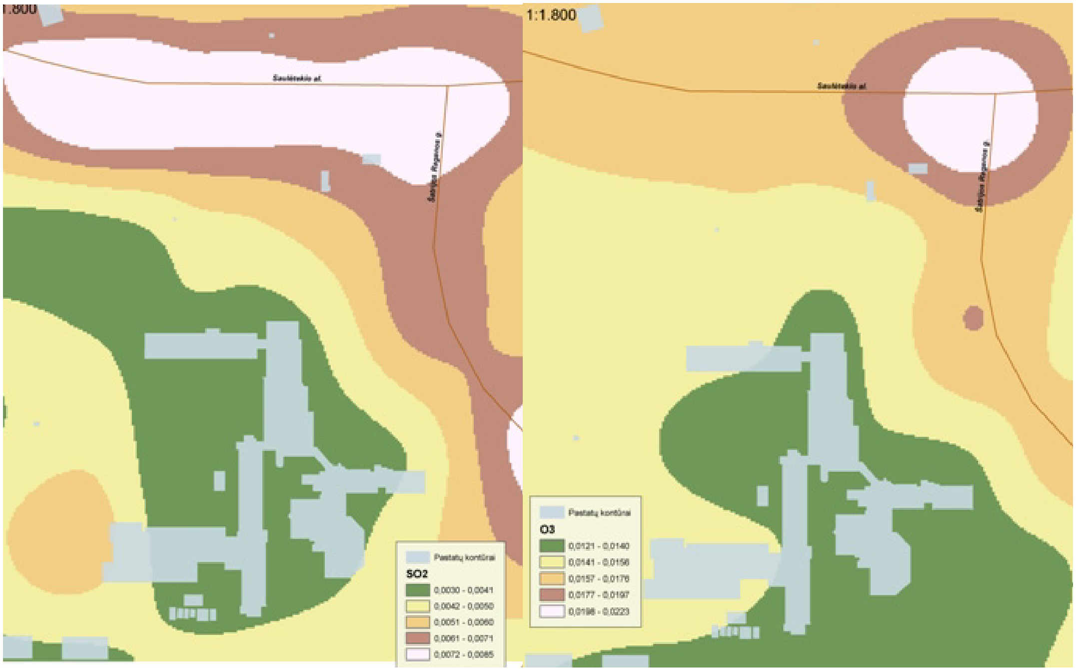


Fig. 7.7.7. Sulphur dioxide and ozone pollution maps in VGTU area

The level of allergens in the premises was measured as well.

7.8. Thermal comfort

Reported on basis of users satisfaction enquiry

The monitoring of the VGTU Main building started in March 2006. Indoor environment quality instrument Metrel M16201 was selected for the monitoring (see Fig. 7.8.1.)

Fig. 7.8.1. The indoor environment quality instrument *Metrel M16201*

This device measures: internal microclimate parameters (volume flow, air velocity, air temperature, relative humidity, dew point temperature, amplitudes of vibration impulses) (fig.7.8.2.)

Illumination

CR 401	CR 402	CR 405	CR 406	CR 407	CR 423a	CR 423b

The vertical axis of the diagram shows Illumination in the premises (lux). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Volume Flow

CR 401	CR 402	CR 405	CR 406	CR 407	CR 423a	CR 423b

The vertical axis of the diagram shows volume flow in the premises (m^3/h). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Relative Humidity

CR 401	CR 402	CR 405	CR 406	CR 407	CR 423a	CR 423b

The vertical axis of the diagram shows relative humidity in the premises (%). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Air Velocity

CR 401	CR 402	CR 405	CR 406	CR 407	CR 423a	CR 423b

The vertical axis of the diagram shows air velocity in the premises (m/s). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Air Temperature

CR 401	CR 402	CR 405	CR 406	CR 407	CR 423a	CR 423b

The vertical axis of the diagram shows air temperature in the premises (^{0}C). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Dew Point

CR 401	CR 402	CR 405	CR 406	CR 407	CR 423a	CR 423b

The vertical axis of the diagram shows dew point temperature in the premises (^{0}C). The horizontal axis shows time interval of the research. Maximum values are red, minimum values are green and average values are blue.

Fig. 7.8.2. The measurements of internal microclimate parameters (volume flow, air velocity, air temperature, relative humidity, dew point temperature, amplitudes of vibration impulses)

The conclusions of an energy audit (performed in 2002) showed that 14-16 °C was the average temperature in premises during a heating season. The indoor air temperature increased by 2-4 degrees after replacement of windows, insulation of roof and renovation of the thermal unit. Now the indoor air temperature meets the specifications of HN 42:2004 requirements. (Table 7.7.1.).

Table 7.8.1. The values of the parameters determining thermal comfort conditions in public and residential buildings provided in specifications HN 42: 2004.

Parameters of thermal comfort	Specified values	
	for cold season	for warm season
1. Air temperature, C	20–24	23–25
2. Appreciable temperature, C	19–23	22–24
3. Temperature difference between the air 1.1 m and 0.1 m above the floor, not exceeding C	3	3
4. Temperature difference between the envelope and the rooms, not exceeding C	2	2
5. Floor temperature, C	19–26	Not specified
6. Relative humidity, %	40–60	40–60
7. Airflow, not exceeding m/sec	0.15	0.25

However, the analysis of volume flow, air velocity and relative humidity shows that current values are lower than those of specifications. Insufficient speed of the indoor volume flow determines lack of oxygen. As a result, indoor hygiene conditions are bad, people feel worse and their productivity decreases. Low humidity in the premises causes discomfort reducing productivity and the mood. Therefore, it was decided to implement a ventilation project (with 50-70 air recuperation). The main purpose of ventilation is to improve the air quality in the VGTU main building, especially in the auditoriums which host many students.

Overall User Satisfaction

Gender specific surveys on indoor environment conditions:

Dissatisfaction percentage	After retrofit
	%
Male occupants	23
Female occupants	35
Total	29

Dissatisfaction percentage occupants after retrofit of the Main building of VGTU.

7.9. Summary

Out of six renovation measures five have been implemented for today; moreover, the seventh measure appeared, i.e. the renovation of ventilation system. Out of all measures only the renovation of the heating system of the Main building of VGTU has not been essentially started. Although, in the very beginning of the renovation, after replacement of window, the convectors in the corridors have been replaced; however, these works were not stated in the financial accounts. VGTU technical direction, office for building maintenance and commissioning operate and maintain the VGTU Main building. They have an operation and maintenance book. Inputs of heat, electricity and water are recorded every day. The monitoring of the VGTU Main building started in March 2006. Indoor environment quality instrument Metrel M16201 was selected for the monitoring.
The actual heating energy consumption for normative period was 482 MWh in heating season 2006/2007. The actual heating energy consumption to compare to the average energy consumption of heating seasons 2002/2003 and 2003/2004 before renovation decreased significantly (56%), particularly by factor 2,30. The energy consumption was 523 MWh in heating season 2007/2008 (heating energy saving (52,7%).

Presently these works have been performed: the area (1089 m^2) of windows and entrance doors has been replaced for 109.696,33 €. Also the partial thermal unit renovation was carried out (renovated for 2.298,06 €). During the renovation of the thermal unit the electromagnetic indicator “Katra” SKM-1M for heat and water quantity was installed. In 2005 the roof of the Main building of VGTU has been insulated (17.020,00 €). In summer 2006 the walls have been insulated (renovated for 106.050,98 €). The renovation of the ventilation system of the VGTU Main building commenced at the end of 2006: the foundation, the room and the steel framework for vertical ventilation shafts were constructed (51.088,97 €). Invoices paid at present status (total amount) are for 286.154,34 €, it makes up 61,9 % of total eligible cost.

VGTU Status at 30.04.08			invoices paid at present status (total amount)	% of total eligible	Total eligible foreseen
Building	Envelope	Change of entrance door	€ 6.154,00	100,0	€ 6.154,00
		Windows	€ 103.542,33	100,0	€ 103.542,33
		Insulation Facades	€ 106.050,98	100,7	€ 105.350,00
		Insulation Roof	€ 17.020,00	100,0	€ 17.020,00
	Plants	Heating	€ -	0,0	€ 185.030,00
		Renovation of thermal unit	€ 2.298,06	100,0	€ 2.298,06
		Renovation of ventilation system	€ 51.088,97	119,9	€ 42.605,61
TOTAL			€ 286.154,34	61,9	€ 462.000,00
TOTAL Reported in ANNEX I					€ 462.000,00

Foreseen and Obtained Energy saving

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, heating, cooling, ventilation	132,1	73,67	1059924	625000

Overall energy consumption

	Before retrofit	After Retrofit Foreseen	Saved foreseen	After Retrofit Measured	Saved measured
Primary Energy [kWh/m^2 a]	284,17	182,92	101,25	186,2	97,97

Overall Economic evaluation

Total extra costs (Foreseen) [EUR]	Total extra costs (Observed) [EUR]	Saving (Foreseen) [EUR/a]	Saving (Observed) [EUR/a]	Payback period foreseen	Payback period observed
893.130	364.619	40.985	24.639	21,8	14,8

Energy costs used for calculation (2008):
Thermal 0,04219 (€/kWh)

7.10. Lessons Learned

Because of the financial shortages the attention was not paid to the third renovation component, i.e. ventilation and in consequence the ventilation system was not foreseen to be refurbished.

In the renovation process economical reasons have lead to the development of 1 project modification. This has been done in close cooperation with the builder and VGTU authorities. The 1 modification is described below. As we saved total 42605,61 €, we suggest if it is possible to use that money for ventilation of the building. In the project proposal ventilation was not foreseen as the mean of renovation. Then the authorities of university are planning to retrofit ventilation system.

8. Evonymos Ecological Library, Athens

Authors: Moissis Kourouzidis; Euphrosyne Triantis; Louizos Elias

8.1. General data

8.1.1. General information

Year of construction: 1890
Year of renovation (start): (i) 1955, (ii) 2006
Number of storeys: Three storeys plus one mezzanine

Heated volume (m^3): 3.780
Cubic contents volume (m^3): 3.180
Gross area (m^2): 1.000
Living area (m^2): 860
Total floor area (m^2): 1.000
S/V ratio: 0.55
Window/glass areas (m^2): 1.1

8.1.2. Site

Location

The building is located close to the central archaeological spaces in Athens, which are being united and enhanced by pedestrian roads. This location is ideal for dissemination purposes as the whole area is very popular and widely frequented by Athens citizens and visitors throughout the year.

Location

Geographic position

Latitude:	37° 58’
Longitude:	-23.43’
Altitude:	50 m.

Climate Conditions

Total Annual Sunshine hours	2818
Annual Heating Degree Days (18 °C)	1110
Temperature	
Winter Average	11.6
Winter av. min	7.6
Summer Average	25.1
Summer Av. max	29.7

8.1.3. Building type

It is a listed building of the 1890 ‘s used as a public library.

8.2. Before retrofit

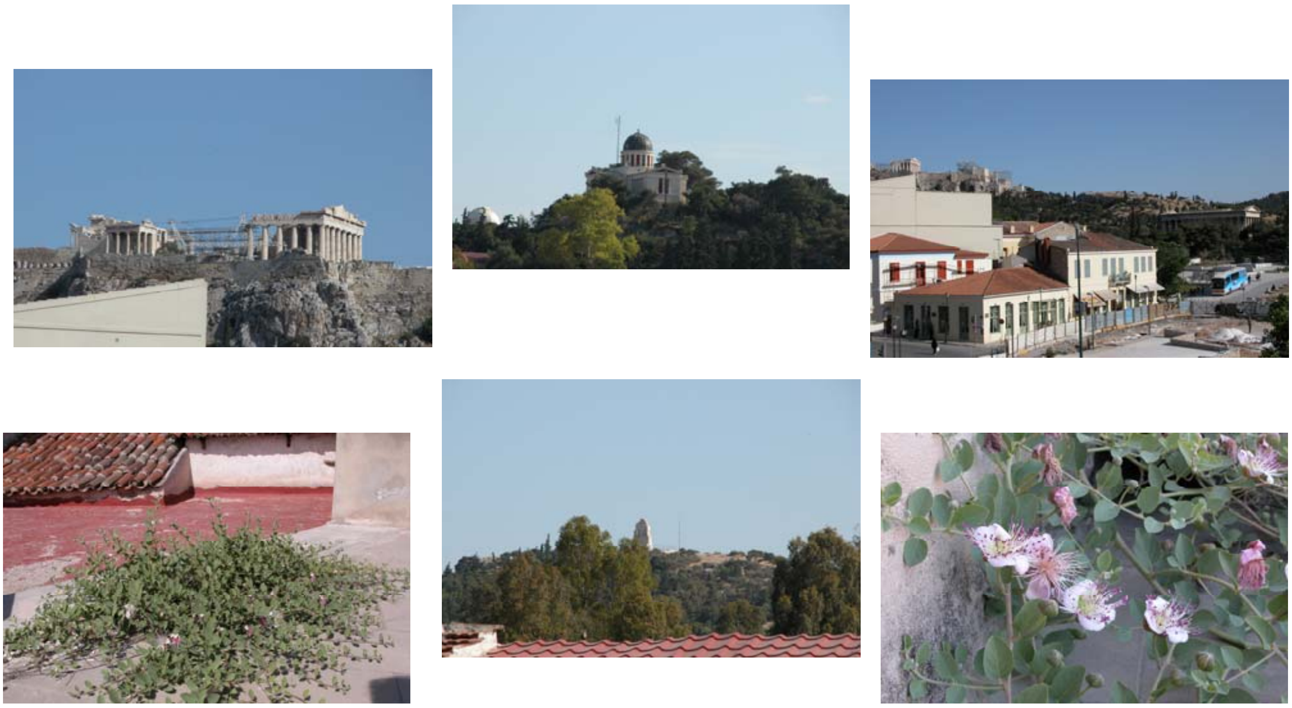
8.2.1. Building construction

The building construction is characteristic of its era. It has 60 cm thick stone walls, and single pane 3,5 m high windows and balcony doors. At present there is no insulation on walls and roofs and there are serious humidity problems in the building. Currently it extends on three floors, a basement, and terrace. The ground floor housed commercial activities while the 1st floor originally a residence, is now used as a library.

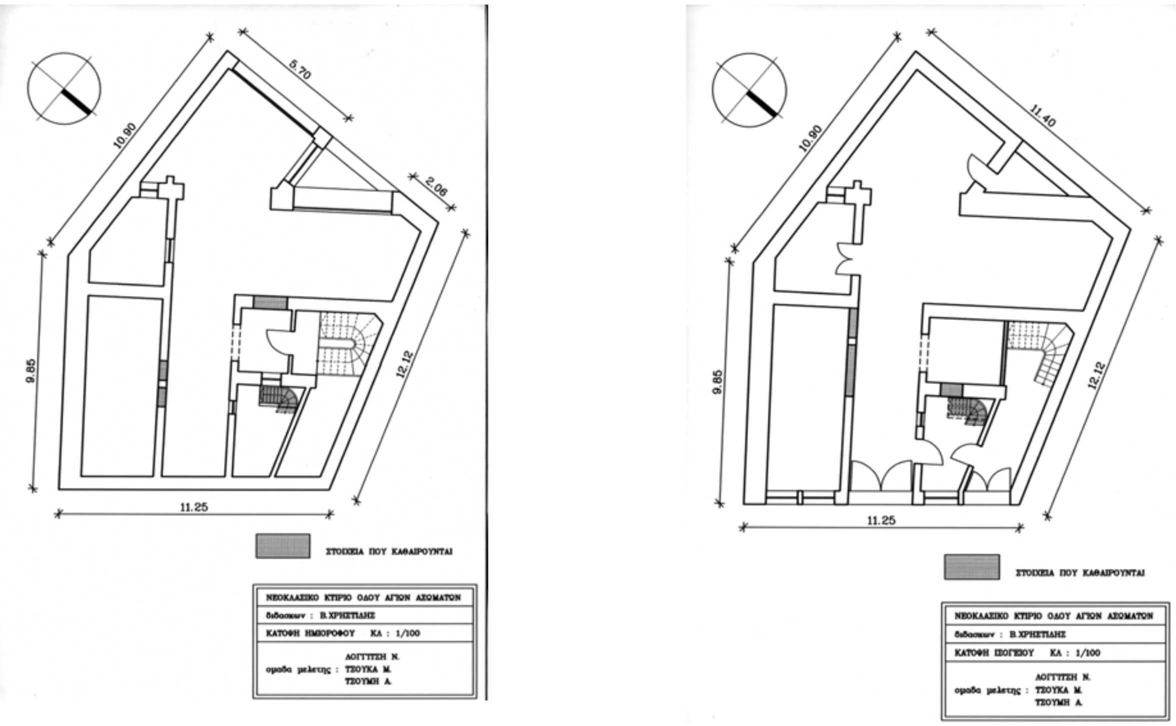
The building has a total floor area of 910 m^2, to which two covered terraces will be added, bringing the total usable surface to 1000 m^2 approximately. Another serious problem is the building facade whites is gravely deteriorated and is in urgent need of renovation.

The building interior

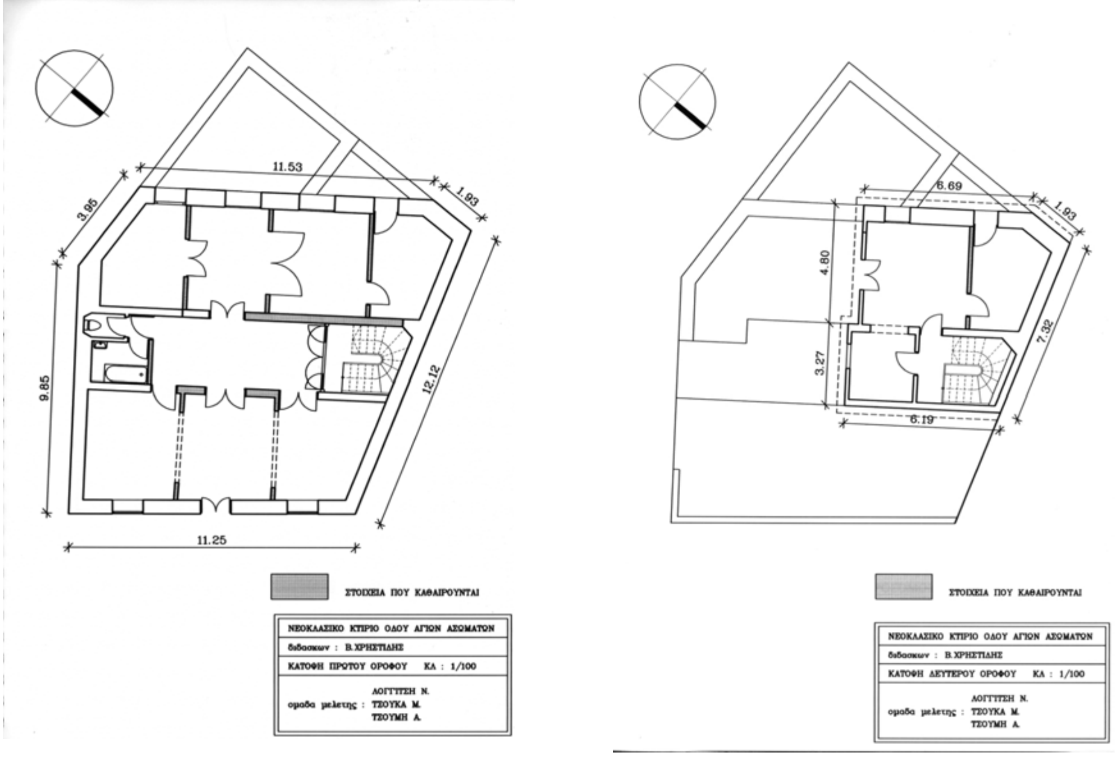
Characteristic details of the building



Main views from the building terrace



Existing plans of the building



Existing plans of the building

8.2.2. Existing heating, ventilation, cooling, lighting systems

Initially the building was heated locally with portable small stoves burning liquid gas. In order to reduce heating expenses, both in equipment and fuel, the stoves served only the places continuously occupied. The remaining building was quite cold, which gave rise to cold drafts and unpleasant cold zones that the users were exposed to when circulating to non-heated areas. Furthermore, the temperature regime was strongly fluctuating with room door opening. During very cold days the capacity of the stoves was not sufficient to keep the internal temperature within comfort levels. Overall the space had strong thermal asymmetries and quite often was under-heated.

Window opening provided ventilation, for both hygienic and cooling purposes. Although this may be in principle a sufficient mechanism for a high percentage of the building operating time, the cold drafts in winter and the street noise especially in summer, gave rise to uncomfortable conditions. Furthermore, the speed of the incoming air that often exceeded the comfort level and the lack of effective mechanisms to control it, gave rise to annoying conditions for the users. These problems resulted in reducing the potential of ventilation to provide cooling. Properly designed ventilation openings were needed in order to remove the warm air without causing any annoyance at the working level.

In summer, because the building remained closed during nighttime, for safety reasons, the heat absorbed by the high thermal mass during the day was not dissipated to the outside but remained in the building elements causing overheating. Thus night ventilation is very beneficial for cooling off the building mass.

Cooling was provided by portable and ceiling fans. This cooling type was quite sufficient for the limited activities and space in use.

Lighting was provided by fluorescent lamps as background lighting enhanced with task lights. The space housing the bookstands and the reading facilities was satisfactorily daylit. However, special daylight design was needed for the circulation space, and the new uses to be housed in the first floor and the mezzanine.

8.2.3. Energy and water use

The energy and water consumption tabulated in Table 1.2.3.1. is estimated based on national consumption levels. The actual consumption is reported in Table 1.2.3.2 but relates to the original limited use of the library. As mentioned in 1.2.2 above, the energy consumed did not suffice to provide comfort conditions to the library resulting in underheated spaces in winter and overheated ones in summer.

	Estimated year (2003)	**Total for the whole building**
Space heating	112 kWh/m^2 a	112000 kWh/a
DHW	3.2 kWh/m^2 a (included in electricity consumption)	3200 kWh/a
Electricity	140 kWh/m^{2}a	140000 kWh/a
Water	1.1 m^3/m^{2}a	1100 m^3/a

The above tabulated values are estimated based on typical consumption levels for offices and raised by 40% to account for longer working hours and different needs of certain uses for this building (such as material recycling labs, coffee shop etc.). Correspondingly the water consumption has been increased by 7%.

	Measured year (2003)	**Total for the whole building**
Space heating	82 kWh/m^2 a	14350 kWh/a
DHW	0 kWh/m^2 a	0 kWh/a
Electricity	3.1 kWh/m^{2}a	435 kWh/a
Water	0.8 m^3/m^{2}a	60 m^3/a

Measured data do not refer to the post retrofit situation of 1,000 m² but to the heated space of the original building (170 m² for heating and 140 m² for electricity) as above mentioned.

8.3. User satisfaction before retrofit

Due to the fact that there was no heating system for the whole building, and temperature differed at various zones depending on local heating sources, internal temperature was not homogeneous and many drafts were created between different spaces which were very disturbing for users, especially in the winter. In the summer, on the contrary, the building was overheated since it could not be sufficiently ventilated, even during the night, for security reasons.
The situation described above created many complaints reported by library users and personnel during questionnaires used before retrofitting started.

8.4. Energy saving concepts

The purpose of the project was to renovate the building and turn it into an ecological library devoted to demonstration, education, and dissemination of low energy and environment friendly technologies in building construction and renovation. This includes traditional and modern techniques of energy and water conservation, ecological building materials, renewable energy systems, and recycling of water, paper etc.

Besides the main function of the library, which includes open shelf reading spaces, new spaces are formed, including conference and seminar rooms as well as workshops on paper recycling, book making and photography, an electronic library and an internet cafe where information on ecological subjects can be obtained. A special open monitoring space is also created, where energy conservation technologies used in the building are demonstrated to the public.

The whole building is completely renovated in the interior. Key feature of the renovation is the addition of new useful spaces, that is:

a) a mezzanine between the ground and 1st floor, in order to take advantage of the double

height of the ground floor (nearly 6 m)
b) the conversion of an existing veranda on the first floor in to an open reading area,
c) the conversion of the terrace in to a sitting area. The outdoor spaces are designed to ensure high quality thermal and visual comfort for the users in all seasons.

All internal spaces are reformed and new spaces added to house diverse activities of the library such as laboratories of photography, CD and DVD production, book binding etc. Moreover an auditorium with a capacity of 80 people is created on the mezzanine, whilst the book stands and reading areas are located on the mezzanine and first floor.

First priority in the renovation curriculum is the minimisation of energy needs with the use of energy efficiency measures and integration of solar technology ensuring simultaneously thermal and visual comfort conditions both indoors and outdoors. Key feature of the renovation design is to accommodate energy efficiency and RES systems and techniques in an integrated design without altering the facades of the building. The energy refurbishment design follows the norms and restrictions foreseen by the General Building Code for listed buildings of this type.

8.4.1. Building construction

- Energy conservation:
- External insulation of walls and roofs
  (4 cm insulation thickness - all external architectural protrusions and balconies were dismounted for the placement of the insulation and then put back).
- Air tight low–e double glazing and night insulation
- Reduction of infiltration with window stripping and tight window frames
- Shading varying according to the orientation of openings
- Shading of the South and Southwest façades with wooden pergolas supporting PV modules
- Ecologically treated wood
- Insulation made of natural plant substances

	Pre-retrofit U-value [W/m^{2}K]	Post retrofit U-value [W/m^{2}K]
Walls	3,4	0,14
Roof	1,4	0,15
Windows	5,7	1,1
Doors	5,7	1,1

8.4.2. Heating

- **Renewable energy integration:**
  - Integration of two sunspaces on the verandas/terraces with openable vertical glazing to eliminate any increase of building cooling load.
  - Solar collectors for DHW (hybrid PV / thermal system for top floor and solar panels for the two lower floors).
- **Efficient energy supply**: Heating energy is supplied by a triple energy burner. The size of the water boiler is 82 kW and it will be shortly connected to the natural gas city network, which is currently renewed. A four-way distributor is used at the boiler outlet to significantly lower the water temperature to the level needed by fan coil units (~ 45-50°C).

8.4.3. Ventilation

- Hybrid efficient ventilation: ceiling fans and earth pipes.
- A centrifugal fan assists natural ventilation. It is installed at the top of the main stairs of the building to reject used air. Additional fans are used to regulate ventilation at each building level.

8.4.4. Cooling

Natural cooling

- Innovative solar chimney / light duct elements,
- Night hybrid ventilation for the warm months

Mechanical cooling

Auxiliary cooling unit. An auxiliary portable cooling unit of 1,5 KW is installed to assist natural cooling in extremely hot days. The unit mostly operates on off-peak low electricity tariffs.

Fan Coil Units (FCU) for the areas of the library. They are mostly placed on the floor of the rooms due to the big clear height (5m) of each space and most importantly of the wall frescoes. Each FCU contains two thermostats, one for air and one for water temperatures. It also carries a humidifier (water spray) downstream the heating-cooling element.

8.4.5. Lighting systems

Daylighting

- Light shelves to enhance daylighting in reading areas
- Light duct (as part of the ventilation chimney)
-

Artificial Lighting

General lighting in the library areas is provided by PL and T5 type eco-fluorescent light fixtures, which exhibit very low electricity consumption.

In areas close to openings the fixtures contain ecological electronic dimmable ballasts (High Frequency Regulated – HFR) and carry light sensors, so each fixture will adjust light output according to the incident light, using as criterion the maintenance of a preset light level on the working surface below it.

In special reading areas local user-operated table lights are used.

8.4.6. BEMS

An intranet with PCs is used for education and information purposes in order to present to students and visitors of the library the energy conservation and environmental systems used in the building and their operation.

Most of the systems installed in the building are controlled by a Building Management system (BMS). The BMS serves 3 distinct purposes:

- Control HVAC, lighting, passive cooling, RES and other systems installed in the building, optimizing their performance
- Collect system operation and energy consumption/production data for analysis and evaluation
- Demonstrate the usefulness of the system itself, as well as the entire energy conscious design of the building.

The BMS system receives input and/or controls the following:

System	**Measurements & controls**
Weather station	Temperature, solar radiation, humidity, lighting level, wind
PV	Recorders, display
Boiler	Thermostats / valves, time
FCU	Temperature, Time, humidification
Fans / Openings	CO_2 sensors, fans, openings, ambient conditions, Time
Lighting	Local dimmer sensors, occupancy sensors, Time
Sunspace	Openings, shading, ambient conditions
Glazing night thermal protection	Rollers (electric motors)
Fire protection and burglar alarm	Fire sensors, occupancy sensors alarms
-	Energy analysis

It is connected via LAN (Ethernet) to the computer system in the library and used for demonstration and teaching purposes.
The sections to follow, defines the details of operation for the BMS.

8.5. Predicted energy savings

Energy saving measures, heating, cooling, ventilation	[kWh/m^{2}a]	Total [kWh/a]
Heating	150	150.000
Ventilation	23	2.300
Solar hybrid cooling	22	2.200
Total heating energy savings	195	195.000

Energy saving measures, electricity	[kWh/m^{2}a]	Total [kWh/a]
Electrical lighting	2.5	2.500
BMS	1,0	1.000
Photovoltaic	0,7	700
Total Electricity energy savings	4,2	4.200

Water saving measures	[m^3/m^{2}a]	Total [kWh/a]
	0,17	175
Total heating energy savings		

8.5.1. Real costs and payback

Energy saving measure/investment	Area [m²]	Total costs [EUR]	Saving [EUR/a]	Pay-back periods [a]
Solar DHW	2,5	2.100	1.078	2 years
P.V. panels	22,24	16.120	673	23 years
Ventilation		6.500	1.186	5.5 years
Electrical lighting		22.500	2.750	8 years
BMS		30.000	1.370	21 years
Window replacement	45	12.500	836	15 years
Total		**89.720**	**7.893**	

8.6. Construction phase description

8.6.1. Building construction

A short description of work done during construction phase follows
The construction procedure described is based on weekly diaries forwarded via the coordinator to the Commission during construction.

	Work	
1.	Reconstruction of the building shell	
	Grindblasting scraping and cleaning of external surface of the building (including scrolls, marble parts and metallic surfaces	
	Dismantling and removing major parts of the roof on the 1st and 2nd floors	
	Scraping and removing veranda flooring (1st and 2nd floors)	
	Scraping and removing points on railings shutters external metallic and wooden windows and doors	
	External insulation and replastering of walls of bats the main and secondary facades	
	Reconstruction and insulation of roof (1st, 2nd floors)	
2	Reconstruction of windows (scraping, installation of low-e double glassing, tight dealing and repainting	
3	Remodeling of the interior Construction of verandas as extension of reading rooms (1st and 2nd floors)	
4	Integration of shading, daylighting	

	and natural ventilation systems	
5	Integration of renewables (P.V. cells and solar collectors	
6	Installation of electrical and mechanical systems, including BEMS	

8.6.2. Heating

As described in 8.4.2.

8.6.3. Ventilation

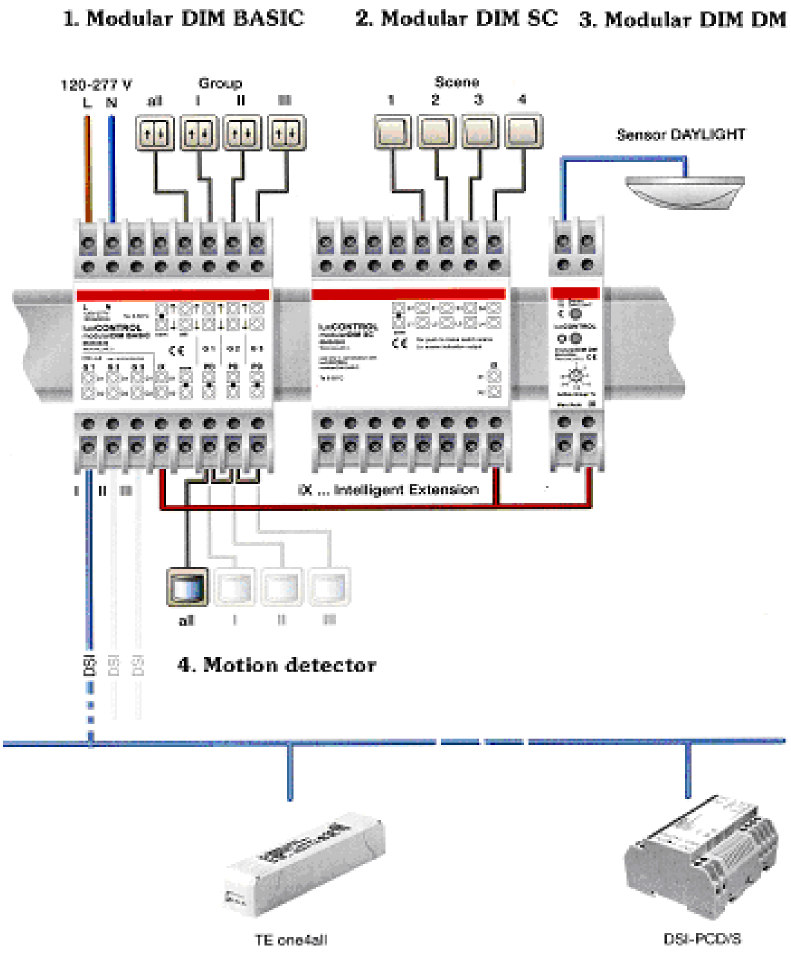
As described in 8.4.3.

8.6.4. Cooling

As described in 8.4.4.

8.6.5. Lighting systems

Lighting systems in the library reading spaces (1st floor) are portable, as there should be no interference with original listed ceiling paintings (see illustration).



Lighting quality and comfort as well as adaptability to a variety of functions and user requirements in addition to energy conservation considerations has led as to the choice of a digital lighting management system by Tridonic.Atco using a DALI protocol (Digital Addressable Lighting Interface) based on a user – friendly PC operation and programming. The description of the system as installed on different levels of the building follows.

8.6.6. Daylight Management System

1. Modular DIM BASIC
   Basic module for manual dimming and switching of 3 self contained DSI groups (all, I,II,III)
   Motion detector inputs for switching each group

2. Modular DIM Scene Control
   Expansion module for Scene Control
   4 light scenes programmed and recalled

3. Modular DIM manual dimming and switching

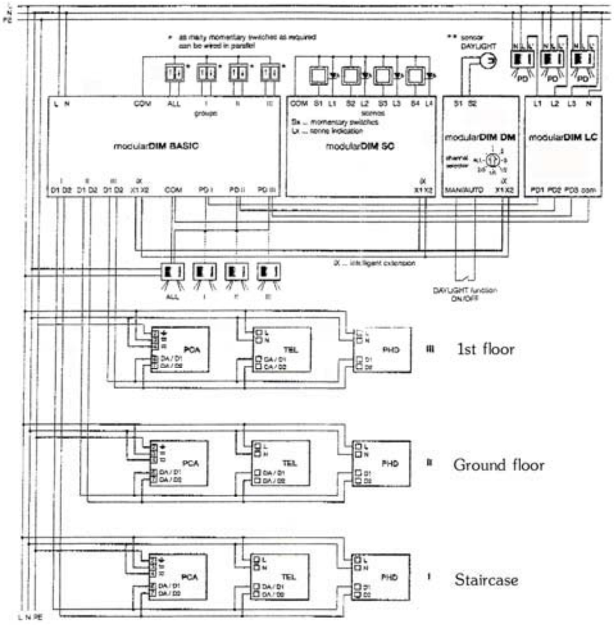
3.1 Expansion module for daylight control

8.6.6.1 DSI Technology

The daylight DSI signal is used for communication between DSI control module and digital dimmable DSI control devices.

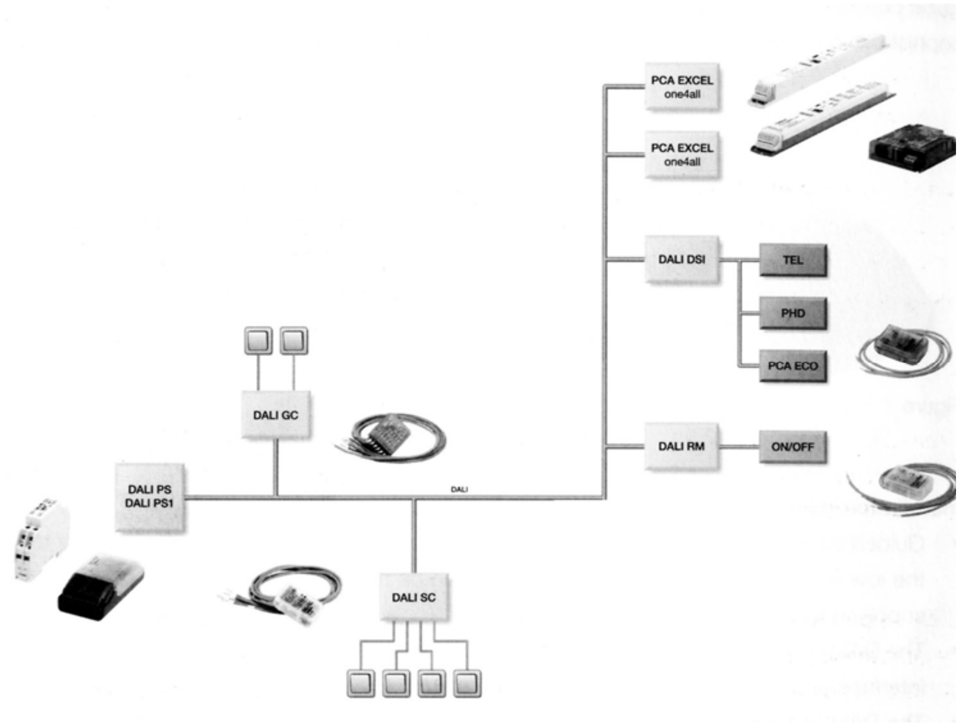
To enable several operating points switches are commented in parallel.
The DSI signal is transmitted by a functional low voltage from modular DIM Basic to electronic ballast.

8.6.6.2 Electric diagram of library (1st floor) and connections of digital devices



8.6.6.3 Management of 2nd floor lighting

An autonomous versalite management system allowing users to choose from all PC stations and positions and from simple wall switches to fully integrated digital building management system (BMS). It is the best solution for a dimmable light control system for the 2nd floor multi-purpose rooms which comprise multi-level luminal groups, requires several lighting scenes and have to mix different types of luminaries.
An operation diagram and port description of the system follows.



1. DALI parts description for 2nd floor Lighting System
Dimmable DALI electronic ballast
Power supply DALI PSI
DALI control system
TridonicATCO DALI GC
Functional description

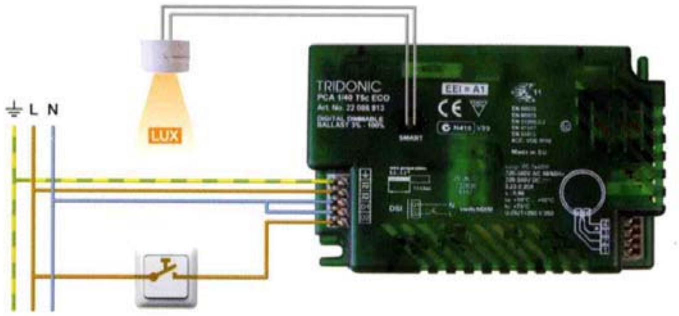
Ultra compact control module for dimming and switching of 2 DALI groups

DALI SCI PC1

The interface module DALI SCI is used to connect PC with WInDim S/W directly to the DALI network

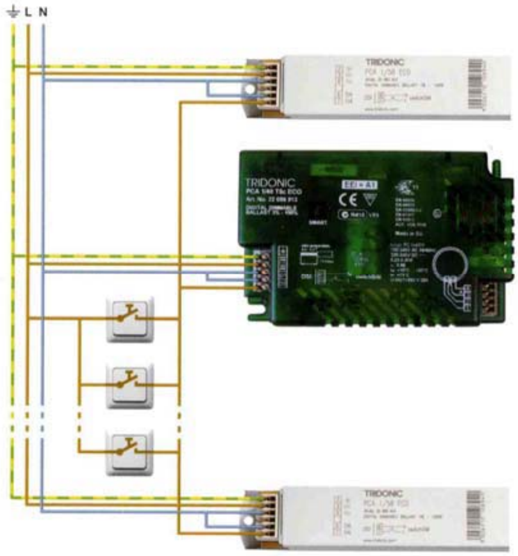
*DALI SC
Ulyta compact control module to set and recall light-scenes from DALI Ballasts with conventional momentary switches

Dimming system

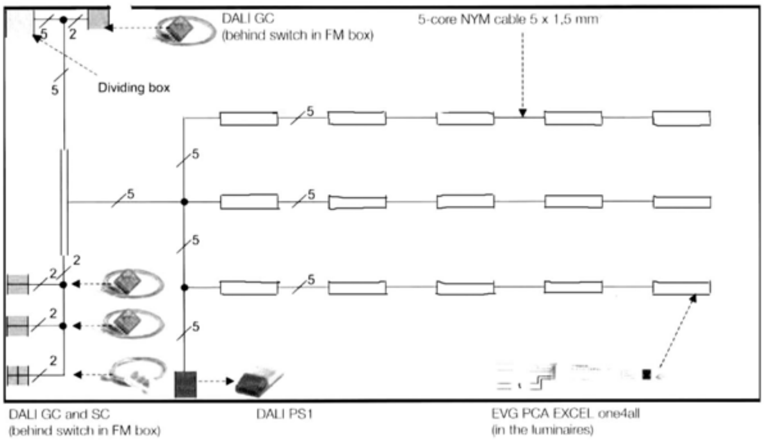


1. Manual dimming and switching
2. Control by natural light

Multi – point control system



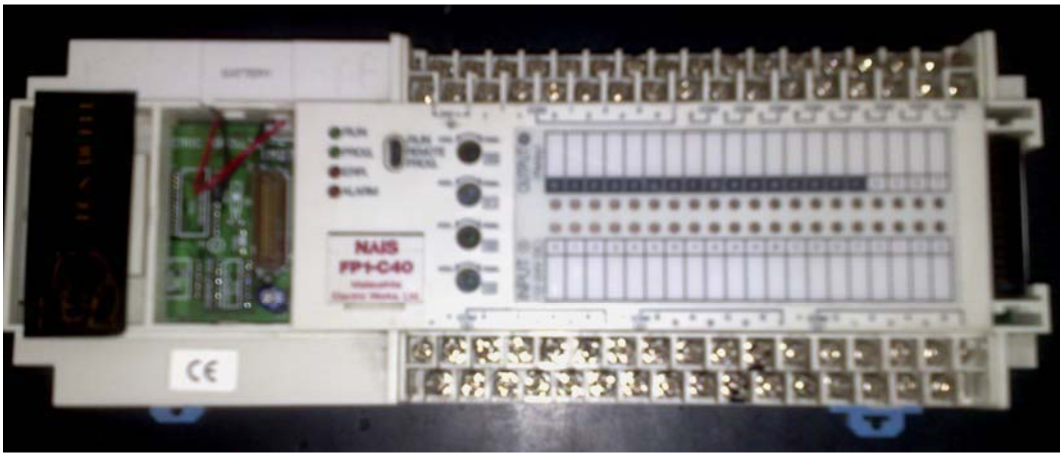
Multi point control



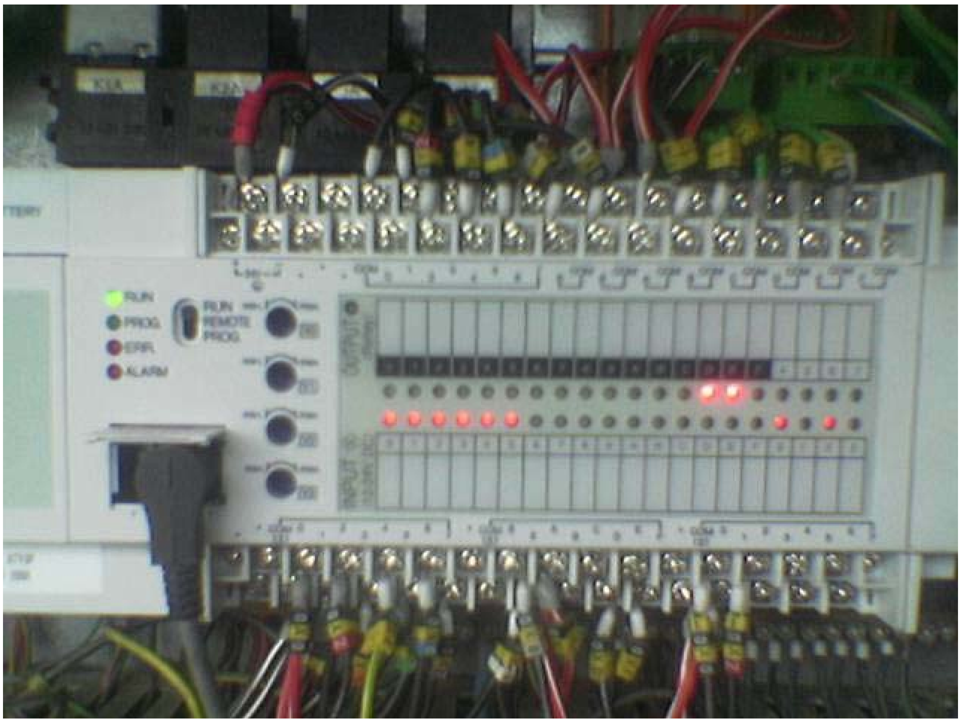
2nd floor electric lighting diagram

8.6.7. BEMS

Part of BMS as well as measurements and monitoring of energy savings is conducted by the light management system. In this project the majority of energy in consumed by electrical lighting. BMS is based on PLC FPI E40 control unit which can have an extension I/O and built-in RAM. Total of I/O points are 40. I/O 24 and O 16. Power supply: 120 VAC – 220 VAC and 12 to 24 V outputs. Miniature relays are TR NPN and TR PNP open collector. PLC used ROM and EEP ROM memory units. An FP1 master unit is used for copying programs.



PLC FPI E40



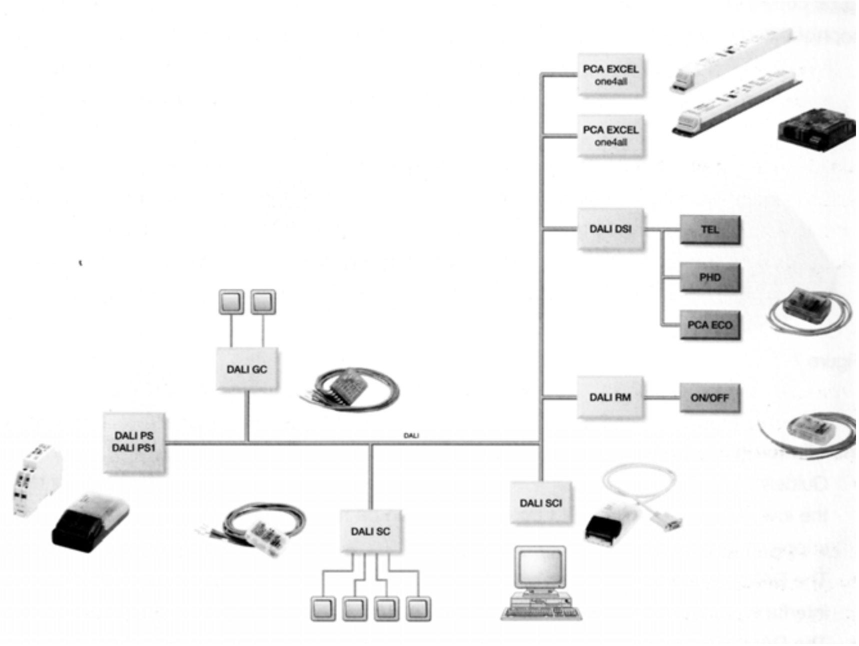
PLC FPI E40 with cabling connection

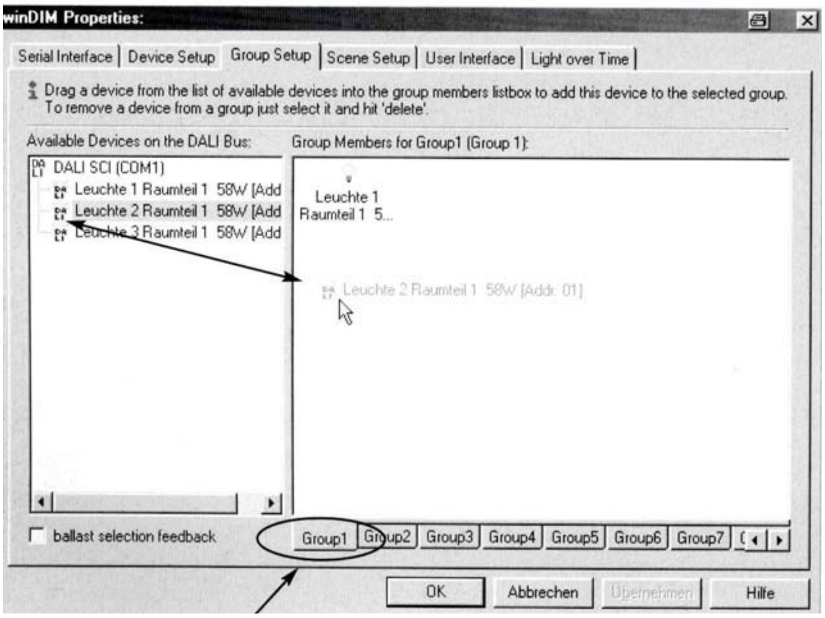
See attached file: POINTS ANALYSIS OF CENTRAL MANAGEMENT AND MONITORING SYSTEM (BMS)

8.7. Monitoring

8.7.1. Monitoring plan

Monitoring plan of lighting management of 2nd floor





Drag a device from the list of available devices into the group members listbox to add this device to the selected group.
To remove a device from a group just select it and hit 'delete'.

Available Devices on the DALI Bus:

DALI SCI (COM1)
Leuchte 1 Raumteil 1 58W [Add
Leuchte 2 Raumteil 1 58W [Add
Leuchte 3 Raumteil 1 58W [Add

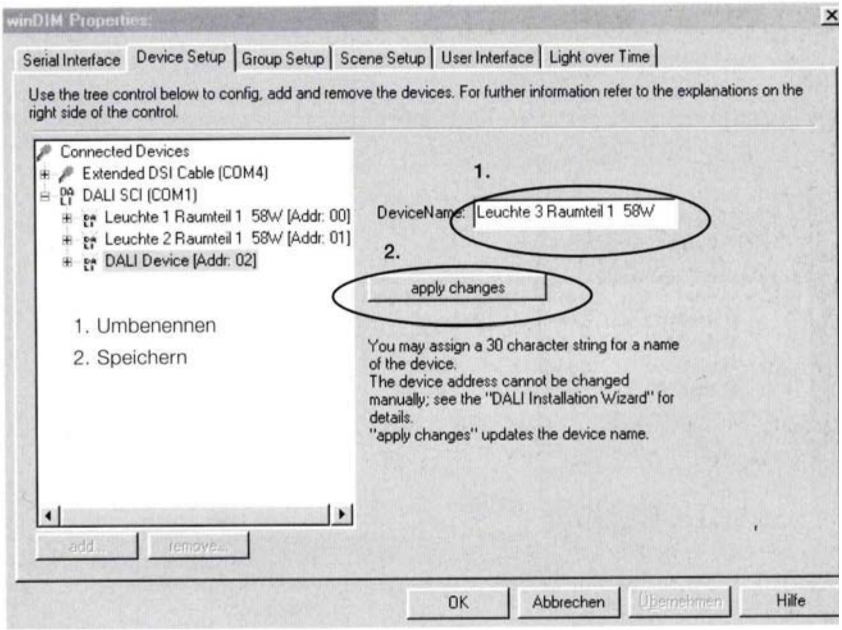
Group Members for Group1 (Group 1):

Leuchte 1
Raumteil 1 5...

Leuchte 2 Raumteil 1 58W [Addr: 01]

☐ ballast selection feedback

Programming groups with winDim S/W
WinDim is a S/W tool with used to control and program the TridonicATCO one4call electronic ECO ballasts and DALI network through the DALI SCI computer interface for windows.



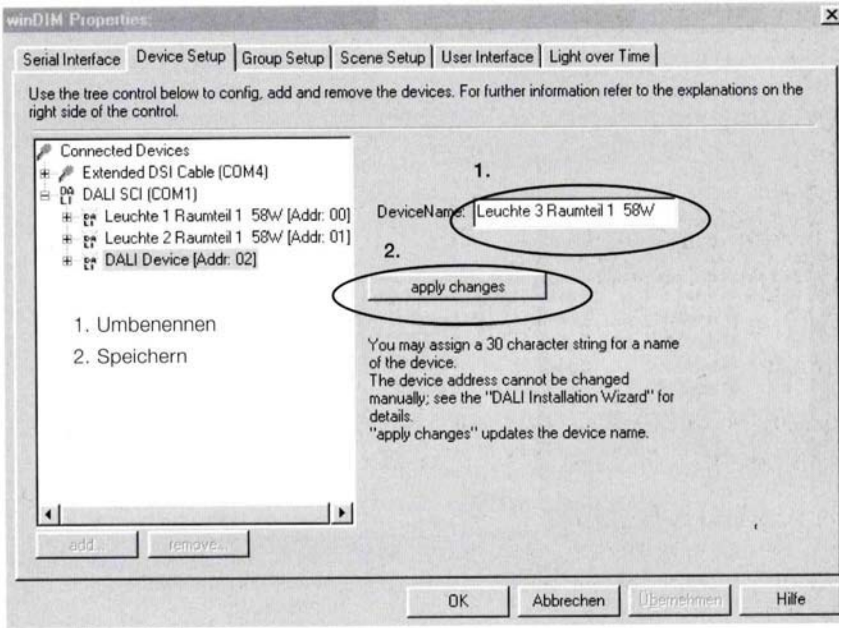
Use the tree control below to config, add and remove the devices. For further information refer to the explanations on the right side of the control.

DeviceName: Leuchte 3 Raumteil 1 58W

1. Umbenennen
2. Speichern

You may assign a 30 character string for a name of the device.
The device address cannot be changed manually; see the "DALI Installation Wizard" for details.
"apply changes" updates the device name.

DALI is a system with a standard protocol for digital DALI devices in the lighting equipment for room-orient light management.
DALI is a part of BMS components
DALI provides a very versatile lighting management solution



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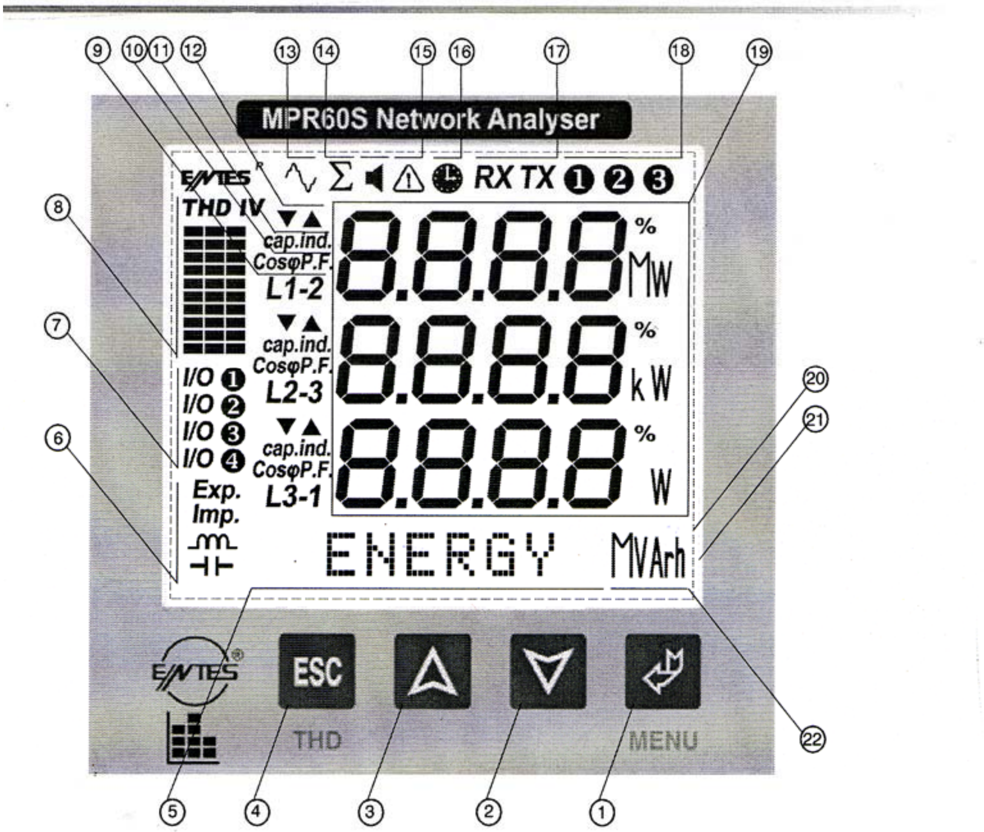
DeviceName: Leuchte 3 Raumteil 1 58W

1. Umbenennen
2. Speichern

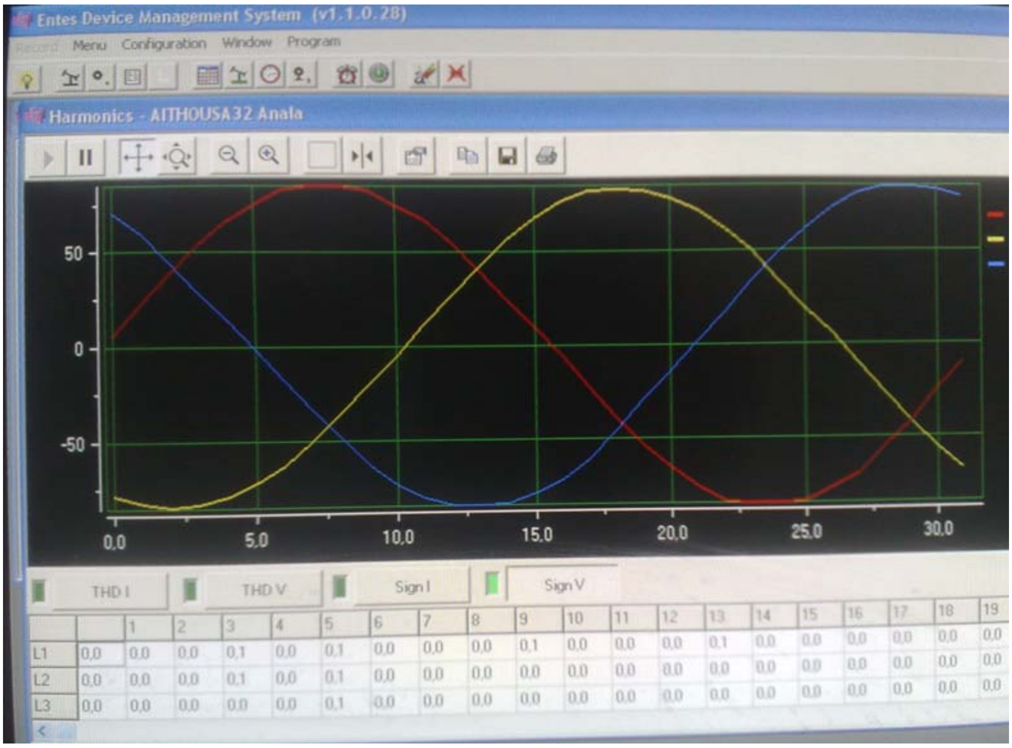
You may assign a 30 character string for a name of the device.
The device address cannot be changed manually; see the "DALI Installation Wizard" for details.
"apply changes" updates the device name.

Start addressing
Addressing is mostly automatic. In Device Setup there is a button for “Start Dali Bms Addressing Wizard”



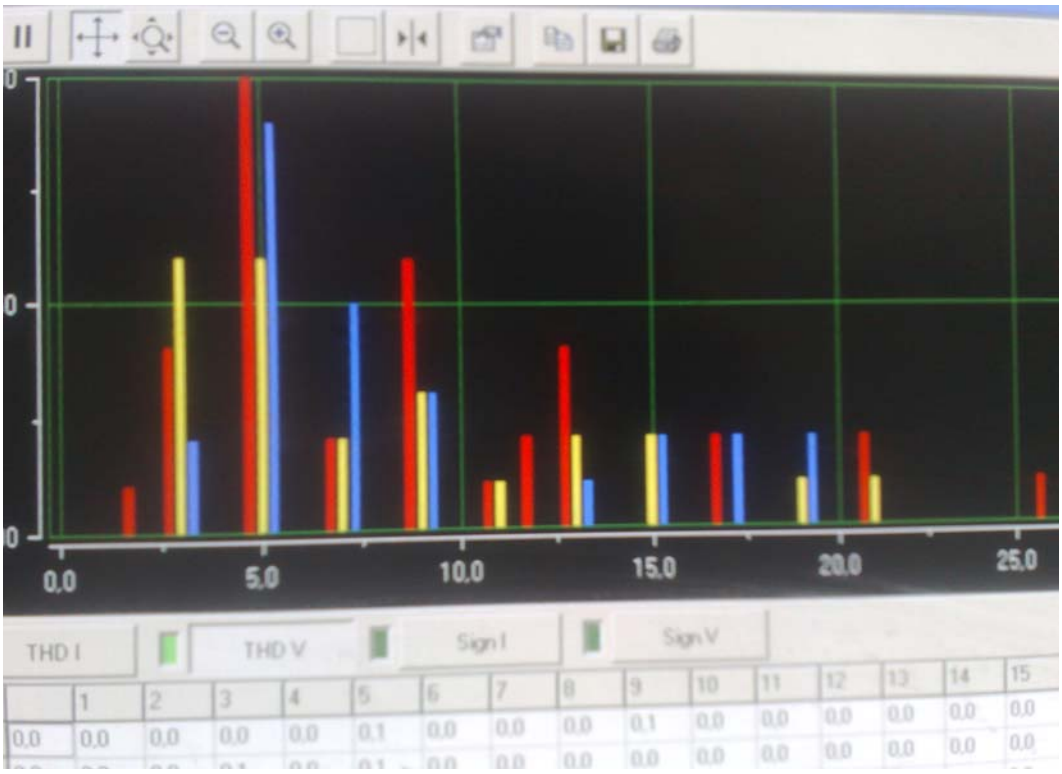
1 .... Menu (ENTER) button.
2 .... Down button.
3 .... Up button.
4 .... ESC button. Exits from a menu or settings at **any time.**
(THD I, THD V can also be displayed)
5 .... Menu / Energy line : Shows the present menu../ It also shows the energy values.
6 .... Shows whether the value in the Energy Menu is Export, Import, Inductive or capacitive.
7 .... Active output is indicated.
8 .... Harmonic bars: The total harmonics of the 3 phases are displayed in bar graphs. The columns represent L1, L2 and L3 phases. Each step indicate 10% increase / decrease V is for the voltages harmonics and I is for the currents harmonics.
9 .... Indicates if the measure is phase to phase or phase to neutral.
10.......... The Cosφ or PF (Power Factor) value of the related phase.
11 .... Indicates if the measurement is capacitive or inductive.
12 .... Min. and Max. symbols for the demand menu.
13 .... Indicates that the harmonics are displayed on the screen.
14 .... Total symbol. Shows the total value of the related measurement.
15 .... Phase sequence failure
16 .... Demand symbol. Shows the demand value of the related parameter.
17 .... PC Communication indicator.
18 .... Phase indication symbols.
19 .... Shows the following measurement values with units.
(V, kV, MV, A, kA, MA, W, kW, MW, VA, kVA, MVA, VAr, kVAr, MVAr %)
20 .... 3.6" LCD Display.
21 .... Backlight.
22 .... Shows the unit of energy values. (kWh, kVAh, kVArh)

Electrical network parameters on PC via converter RS485 to USB



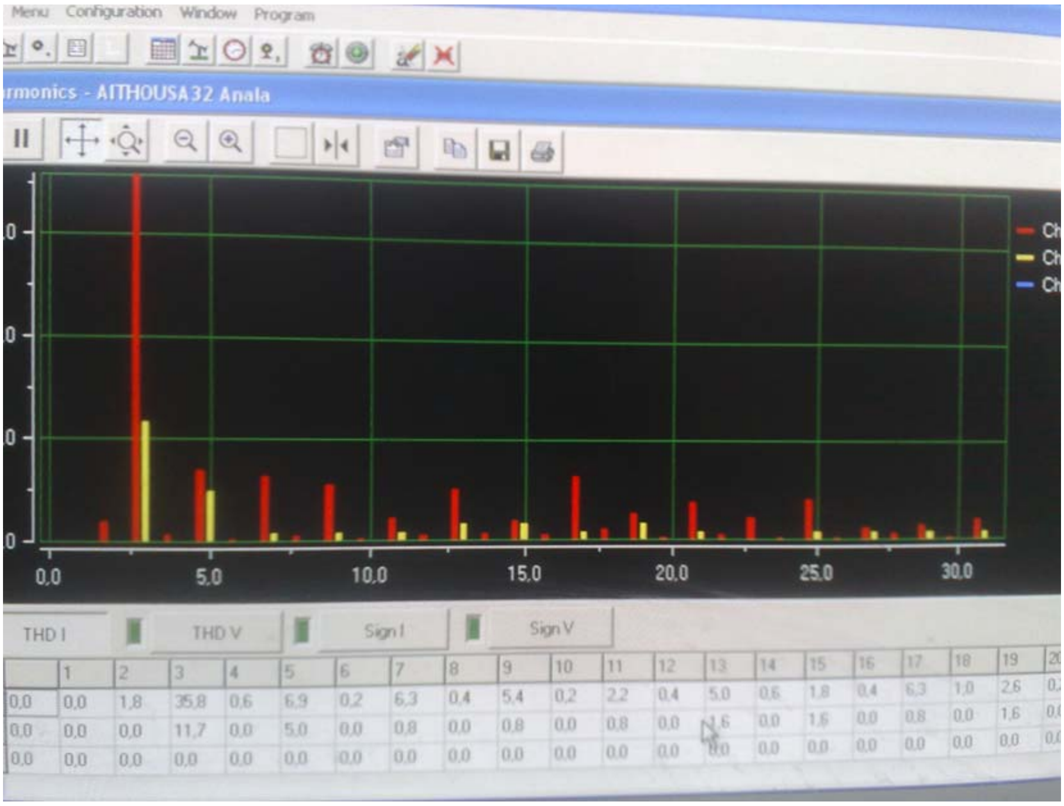
		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
L1	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
L2	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
L3	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Recording parameters with monitoring software MPR-SW SERIES. Three phase indications from grid (PPC) AC power supply



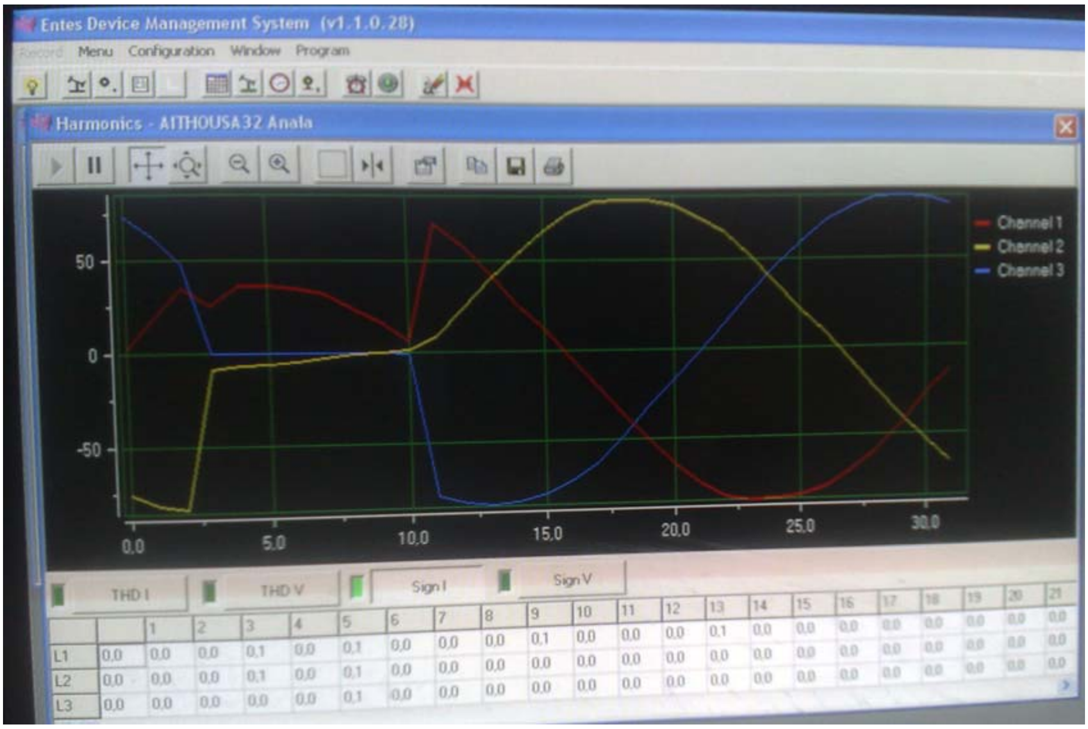
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0
								0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Data display in real time



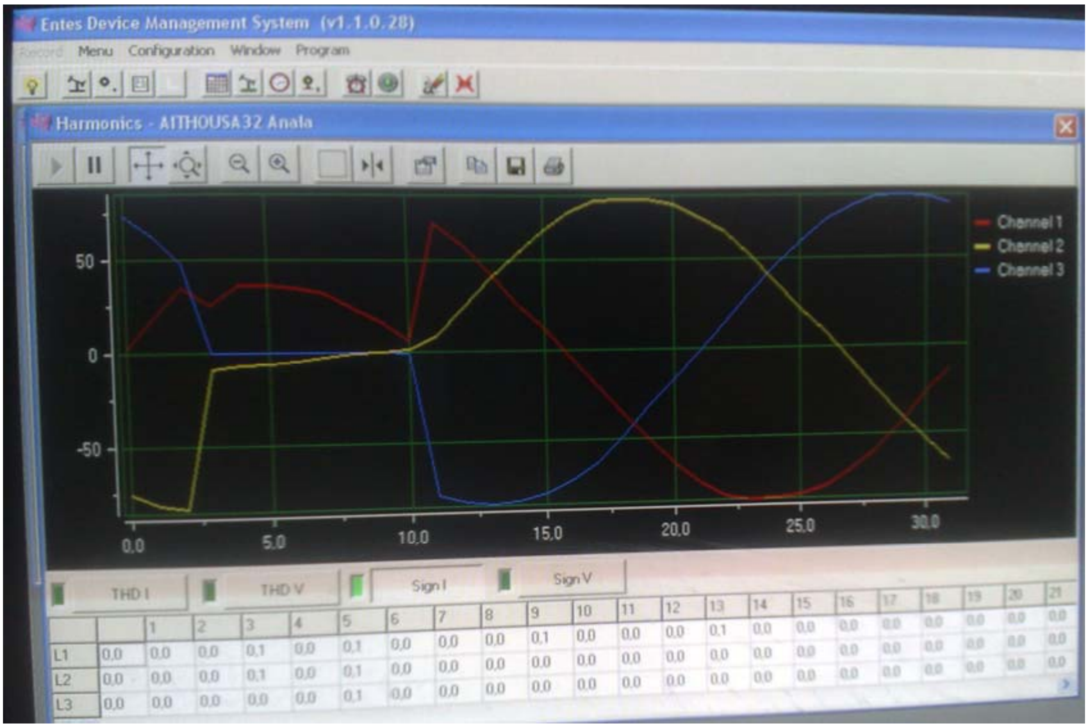
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19
0,0	0,0	1,8	35,8	0,6	6,9	0,2	6,3	0,4	5,4	0,2	2,2	0,4	5,0	0,6	1,8	0,4	6,3	1,0	2,6
0,0	0,0	0,0	11,7	0,0	5,0	0,0	0,8	0,0	0,8	0,0	0,8	0,0	1,6	0,0	1,6	0,0	0,8	0,0	1,6
0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Schematic diagram which represents the harmonic distortion with 90% light dimming



		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
L1	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
L2	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
L3	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Schematic diagram which represents the harmonic distortion with 50% light dimming

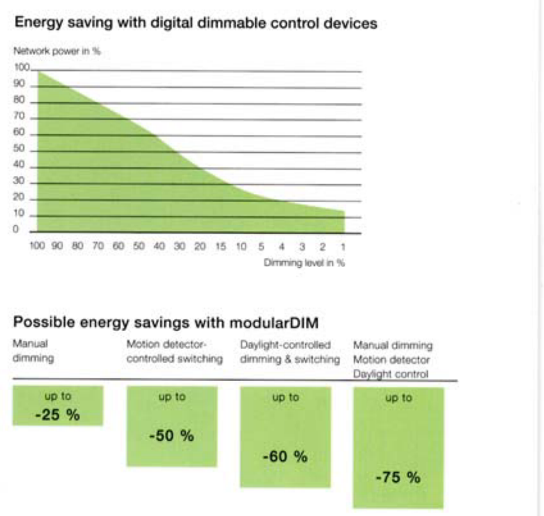


		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
L1	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
L2	0,0	0,0	0,0	0,1	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0
L3	0,0	0,0	0,0	0,0	0,0	0,1	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0	0,0

Current distortion at 90% light dimming

- Energy and Water Consumption
- Temperature drop
- Flows
- Fuel
- Electricity

With the modular DIM system energy savings of up to 75% are realized.
Savings are achieved as a result of both the increased operating efficiency of the lamps as well as the low power consumption of digital dimmable control devices such as the ECO PCA ballasts and TE one4all transformers. The addition of daylight control with presence detectors is a key factor in achieving such high-energy savings.



- Water

- Renewable Contribution
  - Temperature drop
  - Flows
  - Electric Power

Photovoltaic Panels (PV)
PV has been installed on the sunspace roofs, on two verandahs, as shading devices. The direction of PV panels is south with a 30^0 inclination.

FitCraft Production s.r.o. **Photovoltaic panel FCP 170**

FCP 170

The photovoltaic panel FCP 170 belongs to the new generation of panels that are manufactured on the basis of monocrystalline silicone cells with an efficiency of up to 15%. The maximum output of individual panels is ensured by a triple stage production inspection, where the first step is the careful selection of cells that have the same efficiency. Then follows a measuring of individual rows of solar cells (flash tester) and final measuring of the complete panel in the testing device Sun Simulator DO 01. (The simulator tests the panels by a flash of 1000W/m² in the spectrum AM 1.5 on the area of the surface panel) . The use of top quality basic components from renowned manufacturers guarantees high endurance, quality and long life expectancy of the final product. This product is designated for small and large applications for system voltage of up to 1000 V. The FCP panels are EZU certified.

Technical specification		
Weight	kg	19,3
Dimensions	(cm)	1878x800x35
Packing method	Modules	1 per carton
Number of cells	pcs	108
Max. output	W	170W
Module voltage	V	28
Max. system voltage	V	1000

- **Anodized frame**
- **12 x 9 cells**
- **Special hardened glass of panel**
- **Guarantee of material durability 5 years**
- **Guarantee of output 25 years**
- **Output tolerance ± 5 %**
- **Certification: EN 61215**

Example of use

Large area systems
Photovoltaic power plants

Electrical properties FCP170	Mark	Unit	Value
Maximum output	Pmax	Wp	170
Tolerance	Ptol	%	+/-5
Maximum output voltage	Vmpp	V	28
Maximum output current	Impp	A	6,1
Open circuit voltage	Voc	V	31,8
Short circuit current	Isc	A	7,5
Maximum system voltage	Vmax	V	1000
Thermal coefficient	α = +2,1 mA/℃ ; β = -117 mV/℃ ; γ P/P = -0.39 %/℃		
Measuring conditions: Spectrum AM1.5 – 1000W/qm, T= 25℃			

www.fitcraft.cz, tel:+420556770251, fax:+420556770241

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FitCraft Production s.r.o.
VOP 025 Bludovice
Novy Jicin 74101
Czech Republic
EUROPE

FitCraft Production s.r.o.

Specifications of PV panels (1)

FitCraft Production s.r.o. **Photovoltaic panel FCP 145**

FCP 145

The photovoltaic panel FCP 145 belongs to the new generation of panels that are manufactured on the basis of mono-crystalline silicone cells with an efficiency of up to 15%. The maximum output of individual panels is ensured by a triple stage production inspection, where the first step is the careful selection of cells that have the same efficiency. Then follows a measuring of individual rows of solar cells (flash tester) and final measuring of the complete panel in the testing device Sun Simulator DO 01. (The simulator tests the panels by a flash of 1000W/m² in the spectrum AM 1.5 on the area of the surface panel). The use of top quality basic components from renowned manufacturers guarantees high endurance, quality and long life expectancy of the final product. This product is designated for small and large applications for system voltage of up to 1000 V. The FCP panels are TUV and EZU certified.

Technical specification		
Weight	kg	18
Dimensions	(cm)	1575x800x35
Packing method	Modules	1 per carton
Number of cells	pcs	90
Max. output	W	145W
Module voltage	V	47
Max. system voltage	V	1000

TUV SÜD

- **Anodized frame**
- **9 x 10 cells (150 x 80)**
- **Special hardened glass of panel**
- **Guarantee of material durability 5 years**
- **Guarantee of output 25 years**
- **Output tolerance ± 5 %**
- **Certification: EN 61215**

Example of use

Large area systems
Photovoltaic power plants
Water pumps
Telecommunications

Electrical properties FCP145	Mark	Unit	Value
Maximum output	Pmax	Wp	145
Tolerance	Ptol	%	+/-5
Maximum output voltage	Vmpp	V	46,8
Maximum output current	Impp	A	3,1
Open circuit voltage	Voc	V	55
Short circuit current	Isc	A	3,87
Maximum system voltage	Vmax	V	1000
Thermal coefficient	α = +1,29 mA/℃ ; β = -158 mV/℃ ; γ P/P = -0.43 %/℃		
Measuring conditions: Spectrum AM1.5 – 1000W/qm, T= 25℃			

www.fitcraft.cz, tel:+420556770241, fax:+420556770251

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FitCraft Production s.r.o.
VOP 025 Bludovice
Nový Jičín 74101
Czech Republic
EUROPE

FitCraft Production s.r.o.

Specifications of PV panels (2)

8.7.2. Details of PV installation

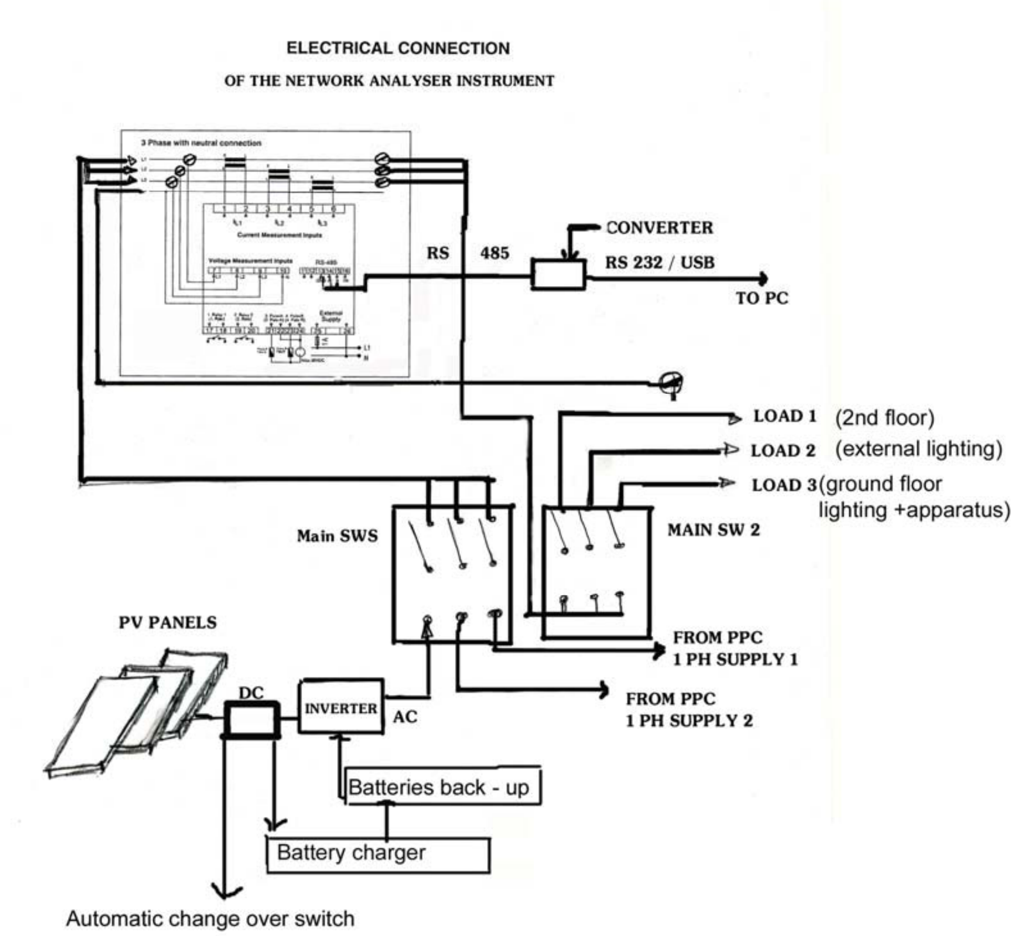
The system is composed of the following PV panels:
8 pcs X 170 W p ea = 1360 Wp
8 pcs X 140 W p ea = 1120 Wp
Total 16 pcs 2480 Wp

2.1.7.1. Dimensions of PV installation

140 Wp 1575 mm X 800 mm = 10,08 m^2
170 Wp 1878 mm X 800 mm = 12,16 m^2

Total effective area 22.24 m^2

Total installed power 2.48 KWp
Power factor of Athens area is 3.4
Electrical energy produced per KWp is 1400 KWh/a
Total solar energy production 3750 KWh/a



8.8. Data analysis

8.8.1. Energy consumption

1.1.8.1. Energy Demand: Electricity

	[kWh/m^{2}a]	Total annual (kWh)
Total electricity	15.2	15.240 E1
Electricity consumed by ventilation	2.9	2.900 E2
Electricity consumed by heating	1.0	1.000 E3
Electricity consumed by cooling	1.5	1.520 E4
Electricity consumed by DHW	1.9	1.920 E5
Electricity of kitchen or special high-energy units	3.2	3.200 E6
Electricity consumed for lighting	4.7	4.700 E7
Primary Energy (Total electricity)	46,2	46.181 PE_E

1.1.8.2. Energy Demand: Thermal

	[kWh/m^{2}a]	Total annual (kWh)
Total incoming heating energy (district heating/solar/gas/oil), measured from the main supply line (temperature drop/flow vs. oil/gas consumption*Heating value)	58.9 (diesel oil)	58.987 T1
Heating energy consumed by ventilation	-	- T2
DHW	2.9 (solar)	2.900 T3 (solar)
Primary Energy (Total thermal)	65	65.052 PE_T

1.8.1.3 Contribution from Renewables

	Total annual	Renewable fraction
Solar Thermal	2.900 R1	60%
PV	3.742 R2	25% R2/E1
Wind power	R3	

1.1.8.3. Water consumption

		Total for the whole building
Water	0.13 m^3/m^{2}a	143 m^3/a

1.1.8.4. Primary energy calculation

		Total for the whole building
Space heating	65 kWh/m^2 a	65.052 kWh/a
DHW	5.8 kWh/m^2 a	5818 kWh/a
Electricity	40.4 kWh/m^2a	4363 kWh/a

1.9 Summary

1.9.1 Foreseen and Obtained Energy and water saving

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, heating, cooling, ventilation	195	210	195.000	210.000

	Predicted [kWh/m^2 a]	Obtained [kWh/m^2 a]	Predicted Total [kWh/a]	Obtained Total [kWh/a]
Energy saving measures, electricity	4.2	14.6	4.200	14.670

	Predicted [m^3/m^2 a]	Obtained [m^3/m^2 a]	Predicted [m^3/a]	Obtained [m^3/a]
Water saving measures	0.16	0.13	170	143

1.9.2 Overall energy and water consumption and improving comfort evaluation

	Before retrofit (or average value of similar buildings, when applicable)	After Retrofit Foreseen	Saved foreseen	After Retrofit Measured	Saved measured
Primary Energy [kWh/m^2a]	703.8 (*)	362	341.8	111.2	592.6
Water [m^3/m^2a]	170				

(*) The conversion factors used for primary energy in these tables were based on Greek authorities calculations in which data before 2004 were used. According to new methodologies the conversion factors can in fact be changed to 0,33 for electricity and 0,9 for oil, based on 2007 data for Greece.

1.9.3 Overall Economic evaluation

Total extra costs (Foreseen) [EUR]	Total extra costs (Observed) [EUR]	Saving (Foreseen) [EUR/a]	Saving (Observed) [EUR/a]	Payback foreseen	Payback observed
124.050	206.000	14.500	18.682	8,5	11

Energy costs used for calculation (2008):
Thermal (€/kWh): 0,071
Electric (€/kWh): 0,178

1.10 Lessons learned

This project was a challenge not only on technical, but also on financial and management procedures. Thus, in addition to the technical challenge of integrating renewable and energy conservation systems to the traditional construction techniques of a listed building, it has been innovative in terms of the combination of private and public sponsors in the retrofitting of a public building

A major lesson learnt by our team was, therefore, that it is often difficult to combine public financing procedures for the restoration of public buildings with the prerogatives of a research project. In the case of Evonymos project, the construction process has been greatly delayed because of the lengthy procedures involved in building restoration financing through the Greek Ministry of Culture, to which the building belongs, as a listed building.

Finally, it should be noted that the introduction of innovative low energy components into the retrofitting of a listed building should not be treated in an inflexible way or as remedy for all types of problems. Each building should be considered individually and innovative features introduced into the overall design concept so that the best possible balance of thermal and visual comfort is achieved and the retrofitted building meets the occupants' practical and aesthetic needs.