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EXAMINATIONOFLOWENERGYRETROFITMEASURES] EUROPEANOFFICEBUILDINGS

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ABSTRACT

This paper describes the methodology used in the Design and Evaluation Group in the project 'OFFICE - Passive Retrofitting of Office Buildings to Improve their Energy Performance and Indoor Working Conditions' funded by the European Commission under the JOULE III Programme. The objectives of the OFFICE project are to promote passive solar and energy efficient retrofitting measures in office buildings. This is done by examining different low energy retrofitting measures in terms of energy, indoor environment and economy and based on this develop global retrofitting strategies and design guidelines. Ten European office buildings are included in the project situated respectively in England, France, Greece, Italy, Norway, Denmark, Sweden, Germany and Switzerland. To exemplify the type of results and analysis produced in the project, selected results from the Danish and the Greek case study buildings are presented.

KEYWORDS
Office buildings, Retrofitting, Passive solar measures, Feasibility study, Design guidelines.

1. CASE STUDY BUILDINGS

The ten case study buildings were selected from an initial set of three candidates from each of the countries participating in the project. The selection was based on the basic requirement, that each of the buildings should represent a typical type of national office building ready for retrofit. In this way it was secured, that building types with as large retrofit potential as possible were chosen. In addition the group of buildings should represent the maximum possible variety with regard to type and pattern of use. The ten buildings are listed in table 1.

The ten case study buildings can be classified in five main types:

- Free standing, core oriented, mostly open plan, heavy structure (Athens, Florence)
- Free standing, skin oriented, mostly cellular, heavy structure (Bern, Copenhagen, Trondheim)
- Free standing, skin oriented, mostly cellular, light structure (Berlin)
- Enclosed, skin oriented, cellular, heavy structure (London, Lausanne, Lyon)

- Enclosed, skin oriented, cellular, light structure (Gothenburg)

To take into account the very different climatic conditions in Europe, the buildings are located in a wide range of climates:

- North European coastal (Copenhagen, Gothenburg, Trondheim)
- Mid European coastal (London)
- Continental (Berlin, Bern, Lausanne, Lyon)
- Southern Mediterranean (Athens, Florence)

The total energy demand of the buildings are ranging from 94 to 717 kWh/m_ per year, while the electricity demand ranges from 65 to 562 kWh/m_ per year. Part of this is due to climatic differences, but the age and the function of the building has a vital influence too.

TABLE 1
List of case study buildings in the OFFICE project

	Name of building	Location	Year of erection	Area: gross / conditioned [m]	Number of occupants
1	DanfossHeadquarter	Nordborg, Denmark	1961	13.400 / 7.000	1000
2	Krokslätt	Gothenburg, Sweden	1989-91	36,971 / 29,889	1000
3	Postbank Berlin	Berlin, Germany	1971	20,200 / 11,930	800
4	Sentralbygg I	Trondheim, Norway	1961	6,440 / 6,200	300
5	Central and West House	London, UK	1870	1645 / 1530	70
6	City West	Bern, Switzerland	1971	25015 / 11683	200
7	LESO	Lausanne, Switzerland	1982	740 / 740	25
8	Cassa di Risparmio	Florence, Italy	1976	1,872 / 1,872	85
9	AGET-HERAKLIS	Athens, Greece	1975	9.292 / 6.403	350
10	LeRecamier	Lyon, France	1987	5,040 / 4,371	160

2. SELECTION OF RETROFITTING TECHNIQUES

The ten case study buildings have been thoroughly investigated through energy audits and hrough short term and long term monitoring programs. Based on these activities, specific retrofitting techniques have been chosen for each of the buildings. The techniques all aim at improving energy performance and indoor environment, using both passive solar techniques and energy conservation techniques.

The examined retrofitting techniques includes activities on three levels- measures, scenarios and packages. Measures are individual retrofitting techniques, such as improved insulation standard, use of solar shading devices and improved heating and cooling systems. In total around 30 different measures have been evaluated (see table 2). Note that the numbers in table 2 refers to the same building numbers shown in table 1. Also note that the categories in table 2 might include more than one measure. Combinations of retrofitting measures within the categories 'Building envelope improvements', 'Passive cooling techniques', 'Electric lighting improvements' and 'HVAC improvements' are called scenarios. Finally combinations of the different retrofitting scenarios, which constitute an integrated retrofitting design approach, are referred to as packages.

TABLE 2
List of measures examined in the OFFICE project

Retrofit measures in the OFFICE Project	Case Study building									
	1	2	3	4	5	6	7	8	9	10
Improve thermal insulation of opaque elements	X		X	X	X	X	X	X	X	X
Replace window frames in bad condition	X		X	X		X	X	X	X	X
Improve insulation standard of window panes	X		X		X	X	X	X	X	X
Reduce infiltration rate	X		X	X		X		X	X	X
Use of mass walls, solar walls, atria or double facades	X							X	X	X
Use of reflective blinds or light shelves				X			X	X		
Use of effective solar shading systems	X	X	X	X	X	X	X	X	X	X
Use of night ventilation	X	X	X	X	X	X	X	X	X	X
Use of exposed thermal mass	X		X							X
Use of ceiling fans					X		X	X	X	X
Use of indirect evaporative cooling			X					X	X	X
Use of natural ventilation	X		X				X		X	
Use of solar protective glazing	X			X						
Daylight responsive control of artificial lighting	X	X	X	X	X		X	X	X	
Control of artificial lighting in response to occupancy	X	X			X					
Use of HF-ballasts	X	X	X		X			X		
Use of modern luminaries or reflectors				X	X			X	X	
Use of task lighting					X				X	
Reduction in installed power for lighting								X	X	
Use of heat recovery on ventilation air	X		X			X			X	X
Reduce ventilation rates	X		X			X				
Reduce running time of mechanical ventilation	X	X								
Improvefanefficiency	X	X	X			X				
Improve mechanical cooling machines						X		X	X	
Use of heat recovery from condenser coil			X			X				
Use of water reservoir for free cooling or for heat sink		X			X					
Use of efficient boiler system					X			X	X	
Use of heat recovery from flue gases								X	X	
Improve HVAC distribution system						X				
Reduce heating set-point	X	X	X							
Increase cooling set-point		X	X							

3. CALIBRATION OF SIMULATION MODELS

A number of exact and validated building simulation tools have been used to simulate the proposed retrofitting measures, scenarios and packages. For energy studies, TRNSYS, DOE, ESP, TAS, Tsbi3, and SUNCODE have been used. For daylight studies, RADIANCE, SUPERLIGHT, and PASSPORT-Light have been used. It was actually proposed, that all design teams should use the same type of simulation tool. However, due to costs of such a procedure, it was decided to let the design teams use familiar design tools.

As it is of vital importance for the OFFICE Project to base guidelines on well validated results, the building models were calibrated against monitored data on energy consumption and temperature pattern. The monitored data used in the calibration process were short term monitoring results from the summer 1997 and the winter 1998. The short term monitored data can be divided into two main types - Building specific data and Meteorological data. Building specific data includes measured energy demand and measured building temperatures e.g. room temperatures. The building specific data were utilised in two ways: As basis for comparison with the simulated results, and as basis for checking the input data for the building model. The meteorological data were used to create the weather files for the simulation tools. Most of the meteorological data were in fact provided from nearby meteorological stations and not monitored on site. Some of the important experiences arising from the calibration process were:

- It was difficult (costly) to measure the different energy services separately. For example to separate total electricity demand into demand for lighting and office equipment. This made calibration of some of the energy services somewhat difficult and emphasise, that buildings should be designed for monitoring, if results should be of high quality.
- The calibration process showed that often the official data concerning set-points and time schedules for the building services, did not correspond with the data used in reality. This highlights the need for be ter quality control of such systems.
- With all the uncertainties involved in a simulation process it is almost impossible to obtain close accordance between simulated and measured results (especia ly energy results). Therefore it is usually more important to calibrate energy patterns than actual figures.

4. RESULTS FOR THE DANISH AND THE GREEK CASE STUDY BUILDING

The results reported for the measures were annual energy demands divided on energy services, economy (saved energy cost, saved running costs, capital costs and simple p ay back period) and thermal comfort (overheating). For scenarios and packages energy demands per month, present value of investment and accumulated frequency curves for indoor and outdoor temperatures, were also reported. In total results for 136 measures, 46 scenarios and 11 packages has been reported by the design teams.

It is impossible to summarise all the results obtained in the OFFICE project on a few pages. Therefore only results for scenarios and packages for the Danish and the Greek case study buildings, are presented. These two buildings represents North European coastal climate and South Mediterranean climate, respectively the coldest and the hottest of the four climate types involved in the OFFICE project. Both Danfoss Headquarter and Aget-Heraklis are multi storey buildings, which facade systems and technical systems, in general are in poor and outdated condition. As a result the energy demand of the buildings are very high and problems with draft, glare and overheating occur. The energetic profile of Danfoss Headquarter is characterised by a very high heating demand and a low cooling demand, while the Aget building is characterised by an extremely high demand for lighting and a very high demand for heating. Table 3 shows the results for the examined scenarios and packages. Note that the results of the OFFICE project shows the consequences of retrofitting for the purpose of saving energy. In a situation where a building should be standard retrofitted anyway, the extra costs of using low energy techniques will be small, thus the investment will be more economical feasible, than if the building was retrofitted for energy saving purposes.

Building envelope scenario: This scenario involves some of the same measures in the two buildings: Improved insulation standard of envelope (opaque elements as well as windows) and reduced infiltration rate. In addition other heating reducing measures such as heat recovery of ventilation air, reduced ventilation rate and reduced heating set-point have been included in the Danfoss scenario. Consequently the total energy demand has been reduced by 69% in the Danfoss building and by 17% in the Aget building. In the Danfoss building most of the saving is on the heating demand (reduced 84%). The ventilation demand is reduced 38%, and the cooling demand is actually increased 1% due to the less use of free cooling (lower ventilation rate). In the Aget building the cooling demand is reduced 19%, while the heating demand is reduced 30%. This puts the attention on the climatic differences between North Europe, where the main priority is to keep heat in and cold out, and South Europe where the priority is the opposite. The envelope scenario are in both buildings economical feasible because of the positive present value of the investment.

Table 3

Simulated results for the Danish and the Greek reference buildings and for scenarios and packages (total gross energy demand, capital cost and Present Value)

Results for the Danish and the Greek case study building	Danfoss Headquarter			Aget-Heraklis		
Scenarios and packages	Energy [kWh/m /year]	Costs [ECU/m]	Pre. Value [ECU/m]	Energy [kWh/m /year]	Costs [ECU/m]	Pre. Value [ECU/m]
Referencebuilding	331	-	-	347	-	-
Building Envelope	103	134	226	288	57	37
Passive Cooling 1	272	99.7	-152	311	14	3
Passive Cooling 2	301	104	-216	-	-	-
Electric Lighting 1	328	19.1	-59	263	85	22
Electric Lighting 2	328	15.6	-42	-	-	-
HVAC	214	47.7	154	278	195	236
Package	95	179.1	77	163	161	138

Passive cooling scenario: Two passive cooling scenarios are examined for the Danfoss building. Scenario 1 combines the existing mechanical cooling system (by ventilation) with lower ventilation rates, and scenario 2 combines no mechanical cooling with the present ventilation rates. In both cases these measures are combined with an external BMS controlled solar shading system, exposed thermal mass and medium reflective openable windows which allow for user controlled natural ventilation (venting) to assists the mechanical system. It can be seen from table 3, that the most energy efficient of the two passive scenarios are the one with mechanical cooling (18% saving versus 9% saving). This is due to the fact, that the energy demand for cooling already is quite low. As a consequence the energy saved by reducing ventilation rates (electricity for fans and thermal energy for pre-heating of ventilation air), are worth much more than the electricity saved by not using mechanical cooling. However it should be emphasised, that it is not necessary to use mechanical cooling to obtain satisfactory thermal conditions in normal office buildings in North Europe. In the Aget building an external solar shading system is combined with night cooling, ceiling fans, free cooling via ventilation air and indirect evaporative cooling. In total 10% of the energy demand is saved in this way. Of this the largest saving is on mechanical cooling (47% saving). Both the Danfoss scenarios are not economical feasible due to the negative present value arising from the very high costs of the openable windows. In contrast to this the Aget scenario is feasible. This reflects both the difference in the costs of the scenarios and the difference between the two climates.

Electric lighting scenario: For the Danfoss building two lighting scenarios are examined. Scenario 1 involves the following three measures: Use of HF-ballasts in all areas plus combined occupancy and daylight responsive control of general lighting in office areas. Scenario 2 involves only HF-ballasts and daylight control. From table 3 it can be seen, that the two scenarios results in the same small saving (1%) on the total energy demand (44% saving on lighting demand and 2% increase on heating demand). This means, that the most cost effective scenario are the one which combines HF-ballasts and occupancy control (lowest costs). The savings are the same in the two scenarios, simply because the daylight responsive control method are so effective, that the lighting will be turned off during most of the day, thus a occupancy control system will have little extra effect. The total energy savings are also small due to the fact, that a saving on internal lighting will result in an increase in the energy demand for heating. As a consequence of the small savings the present value are in both cases negative, thus the investments must be considered poor from a pure economical point of view. The Aget lighting scenario involves improvement of the general lighting system by reducing the installed power, using more effective lamps, reflectors and ballasts (HF) and by using task lighting, daylight responsive control and timer control of general lighting. In this way the total energy demand is reduced 24%, mainly due to the reduction in lighting demand (56%), but also the cooling demand is reduced (16%). As with the Danfoss building the heating demand is increased (9%). Due to the very high lighting demand in the existing building, the present value is positive, thus the investment is feasible.

HVAC scenario: In the Danfoss building this scenario involves reduced air rate and running time of the ventilation system during winter, use of new effective fan systems and use of new openable windows which allow for user controlled pure natural ventilation during summer. As a consequence the total energy demand is reduced 35%, divided on a 36% reduction on the heating demand, a 99% reduction on the cooling demand and a 83% reduction on the ventilation demand. Mechanical cooling is almost completely avoided, because the mechanical ventilation system is shut down during the summer. The present value of the investment is positive, thus the investment is feasible. In the Aget building this scenario includes: Use of a BMS to control the HVAC system, decreased heating set-point, new boiler system and heat recovery from ventilation air, boiler flue gases and condenser coil. The total energy demand is reduced 20% divided on a approx. 30% reduction on both heating and cooling demand. The present value show the highest positive value of all, meaning that the investment is the most feasible of the scenarios and packages examined for the Aget building.

Package: The packages involve the most promising of the measures from the scenarios. For the Aget building this means all the measures from the scenarios described above. For the Danfoss building most of the scenario measures are included except for: Medium reflective glazing, reduced ventilation rate, exposed thermal mass, pure natural ventilation during summer, use of HF ballasts and use of occupancy responsive control of lighting. Consequently the total energy demand are reduced 71% in the Danfoss building and 53% in the Aget building, resulting in a positive present value varying from 77 ECU/m_ to 138 ECU/m_. In the Danfoss building the energy reductions are divided on cooling demand (100%), heating demand (82%), ventilation demand (56%) and lighting demand (29%). In the Aget building the reductions are divided on lighting demand (56%), cooling demand (48%) and heating demand (42%).

5. THE EU OFFICE PROJECT

The outcome of the OFFICE project, including results and analysis from the Design Evaluation Group, are described in the project reports, which will be publicised during 1999. The EU OFFICE project is co-ordinated by University of Athens. The Design and Evaluation Group are co-ordinated by The Norwegian University for Science and Technology and Esbensen Consulting Engineers, Denmark.