The Rockwool International A/S low energy office building – Thermal envelope performance and indoor environment

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1. INTRODUCTION

A new research centre has been build for 130 employees in Rockwool International A/S' R&D department in Hedehusene, Denmark. The architect is Prof. Jens Arnfred, Vandkunsten, and consulting engineer is Erik K. Jørgensen. Figure 1 shows a photo of the building seen from northwest and a plan of the building. The total floor area is approximately 4000 m^2 comprising an open office environment and test rooms. The building was inaugurated in the summer 2000.

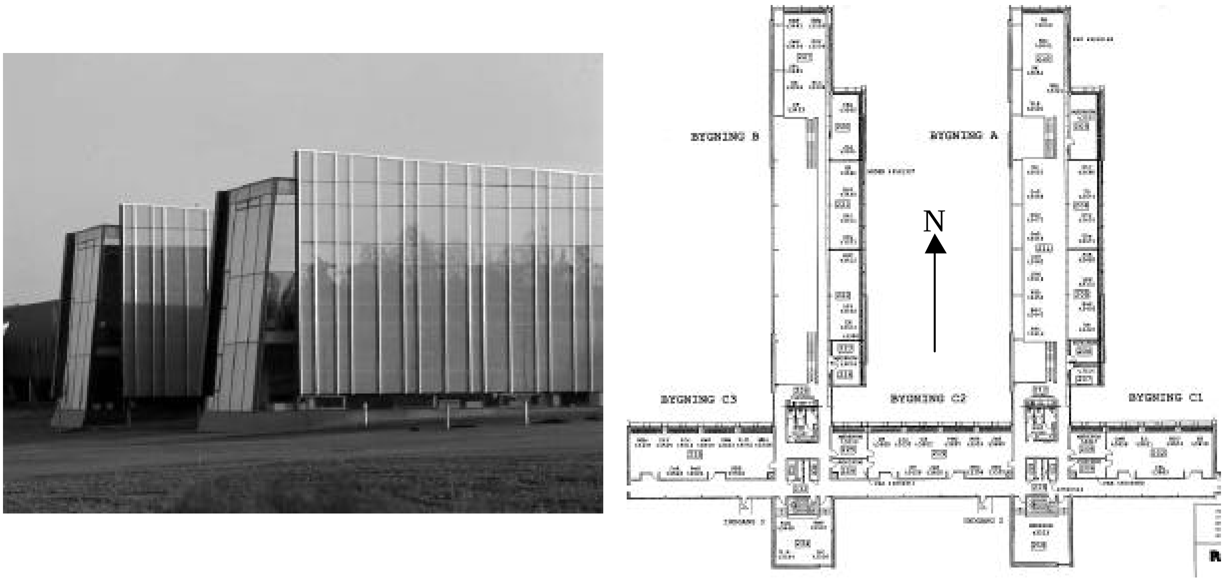

Figure 1. Photo and plan of Rockwool International A/S' research centre, Hedehusene, Denmark

The goal was to create a low energy office building with a good quality of architectural design and a space heating demand of only 1/3 of the building code requirement – approximately 50 MJ/m^2 per year. The indoor environment should be pleasant regarding temperature, daylight and air quality obtained by means of controlled natural ventilation.

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The low energy consumption for space heating is a part of the main goal of minimising the environmental impact from the building. Life cycle analyses of materials, constructions and the building process have formed the basis for choice of materials and the building system.

A key issue was also to have the building performance documented by independent organisations. For this reason the Technical University of Denmark and the Danish Building Research Institute was asked to be responsible for the measurements and evaluation of the results. The energy consumption, the indoor climate parameters, the architecture and the other relevant parameters should be continuously shown for the public at the Internet.

Finally Rockwool wanted to show the capacity of passive fire protection of the constructions.

2. BUILDING CONSTRUCTIONS AND TECHNICAL INSTALLATIONS

The very strict limits set up for the project should be met with super insulation of the thermal envelope with 500 mm Rockwool roof insulation, 450 mm Rockwool facade insulation, 250 mm Rockwool insulation of foundation and cellar, 250 mm Rockwool insulation under the floors and three-layer low-energy windows with gas filling and coating (over all U-value including frames = 0.85 W/m^2 K).

Special focus has been put on minimizing the thermal bridges in the constructions and at all joints and to achieve a very airtight building with an infiltration rate of maximum 0.01 ach/h.

The electrical consumption is kept at a minimum with automatic lights control and controlled natural ventilation as the main source for cooling and ventilation.

Finally, solar panels for heating of water are installed on the roof.

2.1 Constructions

The main design of the roof is shown in figure 2 below.

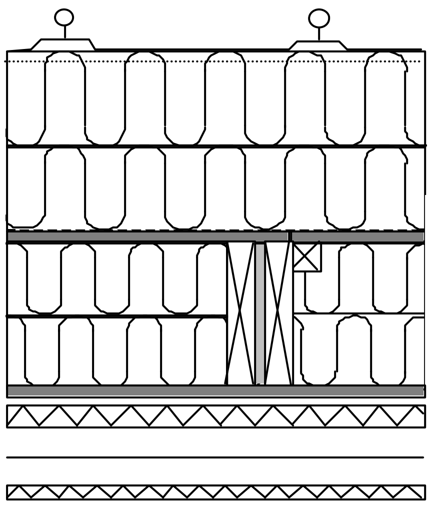

Figure 2. Cross-section in the roof construction.

The main construction is based on Rockwool filled plywood cassettes, which at the outside are insulated with Rockwool Roofboards covered with aluminium plates. At the inner surface the cassettes are fire insulated with Rockwool Conlit. There is no water vapour barrier in the construction. The inner side of the roof is made airtight by sealing all the joints.

The construction of the facades is similar to the roof. The outer surface is either Rockpanel or transparent glass. The U-values of the construction are shown in table 1.

Table 1. Insulation thickness and design U-values for the thermal envelope compared to the requirements in the Danish Building Code from 1995.

Construction	Rockwool Building 2000		Danish Building code 1995	
	Insulation thickness	U-value	Insulation thickness	U-value
	mm	$W/m^2 K$	mm	$W/m^2 K$
Roof	500	0.08	200	0.2
Façade	450	0.09	200	0.2
Floor	250	0.10	100	0.3
Window centre	-	0.40	-	-
Window overall	-	0.85	-	1.8

2.2 Heating and ventilation

The heating system is a traditional water system with radiators and convectors supplied with hot water from two gas boilers. The outdoor temperature controls the supply temperature and a time control of the set point allows for night and weekend lowering of the indoor temperature.

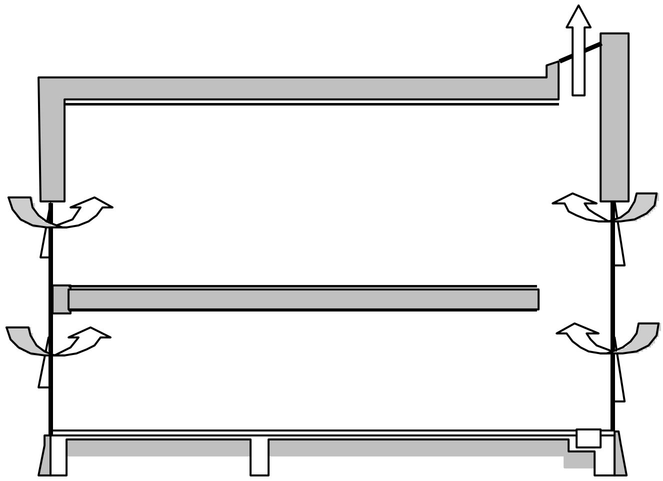

Figure 3. Sketch of the natural ventilation principle. The arrows show where the motorised openings are situated in the facade and in the roof.

Ventilation of the building is solely performed by natural ventilation except for mechanical exhaust from bathrooms and small kitchen areas. The principle of the ventilation is shown in figure 3. A computer controls the opening and closing of the windows based on a number of different parameters (temperature, outside wind speed, rain, wind direction, clock functions, etc.). In summertime the natural ventilation is used for night cooling of the building. All the openings can be operated manually by the users.

2.3 LCA- thinking in building design

The "Building 2000" was designed, using "Manual in Environment Friendly Design" (Danish Association of Consulting Engineers, 1998) involving LCA-modelling of primary construction parts, for example:

- LCA-screening of different types of load bearing constructions. Steel/wood cassette was chosen in favour of reinforced concrete and wood.
- Elimination of unwanted materials and construction elements. PVC-free wiring was preferred together with central heating in favour of electrical heating, and solar panels were chosen for hot water supply.
- All material used or scrapped during construction was accounted for; altogether 71 different material classes were used. The work was finished with a Life Cycle Inventory of the whole building.

Primary energy use is 126 kilo oil equivalent per m^2 and the annual expected energy saving per m^2 is 2.5-3 kilo oil equivalent per m^2 leading to a payback time of 30 years for the total building if only the savings are considered.

3. ENERGY PERFORMANCE

3.1 Overview of the measurements

The measurement system comprises:

- Climatic data (global solar radiation on horizontal and on vertical north, east, south and west as well as the outdoor temperature)
- Construction data (11 humidity sensors, 5 heat flux sensors and 74 temperature sensors in the roof, walls and floor)
- Indoor environment (24 temperature sensors, 2 relative humidity sensors and 2 CO2 sensors)
- Energy (7 kWh-meters and 2 energy meters for the heating system)

All sensors are scanned every 10 seconds except for the humidity sensors in the constructions which is scanned only once a day. The measurement program automatically creates hourly mean values, which are the only data saved. Selected hourly values can be watched directly on the Rockwool homepage www.rockwool.com/environment/default.htm

3.2 Measured energy consumption

Evaluation of the energy performance of the office building has been concentrated on one half of the total building with detailed registration of internal loads from PC's, artificial light etc. as well as registration of the number of people in the building. On average about 60 people are on work each day. The average internal loads are approximately 37 kW in the working hours corresponding to 22 W/m^2 floor area.

The natural ventilation is not continuously monitored, but one week of tracer gas measurements in February 2001 showed a very low average air exchange rate of only 0.13 l/s pr. m^2 floor area corresponding to 0.14 ach/h. This air change rate has indirectly been confirmed for other periods by evaluation of the continuous measurements of the CO_2 content in the indoor air.

Figure 4 shows the calculated and measured energy consumption for the period January 1st to November 30th 2001. The initial calculated energy consumption (1st column) is obtained with the BV 98 program (SBI, 1998) based on the method described in EN 832 (EN 832:1998) using the measured climatic data and indoor temperature set points. Comparison of the initial calculations with the measured energy consumption shows large differences especially in the spring and autumn months, where the solar radiation becomes important.

There can be several reasons for the deviations, but the two main reasons are 1) the utilisation of the internal loads and the solar gains, which in an office building always will overlap and 2) higher total U-values of the windows than initial calculated.

Concerning utilisation of the internal gains calculation method (EN 832) is primarily developed for residential buildings and thus uses a more favourable calculation of the utility factor than should be expected in an office building (not the same coincidence between internal loads and solar gains). This explanation is further supported by the temperature curves shown in figure 6.

The overall window U-values have recently been recalculated with the new standards that include the thermal bridge effects in a more correct way leading to a calculated increase in U-value from 0.85 W/m^2K to approximately 1 W/m^2K.

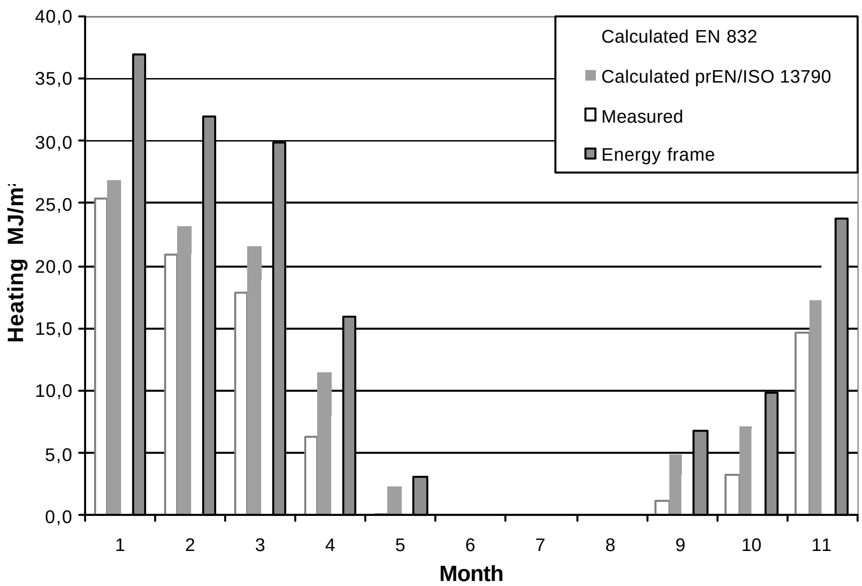

Figure 4. Energy frame, calculated and measured energy consumption for space heating. The calculations is made with the measured indoor temperatures and outdoor climate. (Please note that the measured energy consumption for month 1 – 4 is a “best guess” based on the over all gas consumption).

For evaluation purposes calculations based on prEN ISO 13790, which uses a more realistic model for the utilisation factor for office buildings, have been included in figure 4. A closer agreement between measurements and calculations with prEN ISO 13790 is observed. Investigations for explanation of the remaining differences are still going on. For comparison also the energy frame requirements (BR 95 1995) is shown in figure 4. The energy frame is an annual demand, which for this case has been distributed over the months in the heating season proportional to the calculated energy consumption (prEN ISO 13790).

4. INDOOR ENVIRONMENT

4.1 Indoor climate

Several temperature sensors in different heights, indoor relative humidity sensors and CO_2 sensors monitor the indoor climate and environment on each storey. The indoor environment is further evaluated by questionnaire investigations carried out in February and August.

Figure 5 shows the indoor temperatures in a summer month (July 2001) compared with the outdoor temperature. In general the goal of not exceeding the outdoor temperature with more than 6 °C in the working hours is met, but the figure also shows the large potential for cooling by means of night ventilation. However, this did not work properly until September 2001, which explains the relatively high indoor temperatures.

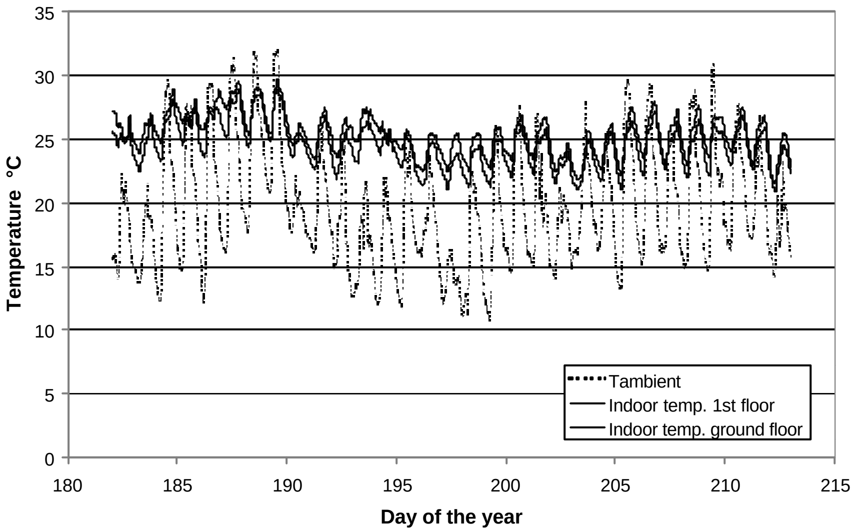

Figure 5. Indoor and outdoor temperatures in July 2001.

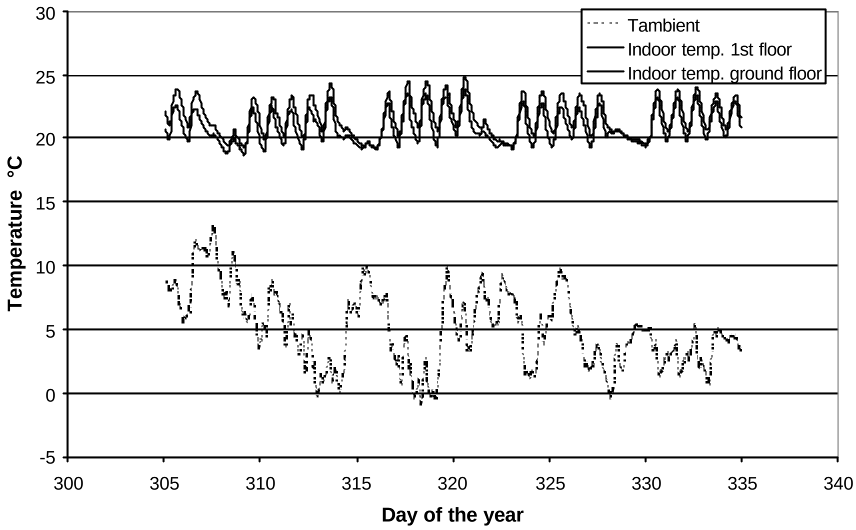

Figure 6. Indoor and outdoor temperatures in November 2001.

Figure 6 shows the indoor temperatures in November 2001 compared with the outdoor temperature. It can be seen that the maximum indoor temperature during the working hours is about 24 °C, which is above the set point of the heating system (22 °C). This shows clearly that the internal loads and the solar gains cannot be fully utilized even in November, which however is predicted by the calculation model (EN 832). Figure 6 also shows the effect of the lower set point at night and weekends, where the temperature drops to approximately 18 °C at the ground floor and 20 °C on the 1st floor. However the effect on the energy consumption seems to be minimal, as it is a very short time the temperature is at the lower set point (17 °C).

4.2 Indoor air quality

The indoor air quality can be evaluated from the CO_2 measurements shown for November 2001 in figure 7 below. Due to investigations of draught near the floor level the planned airing twice a day have been stopped in the last period of November, which is clearly seen in the figure where the CO_2 level becomes close to the limit of 1200 ppm. Normally the concentration is below 1000 ppm.

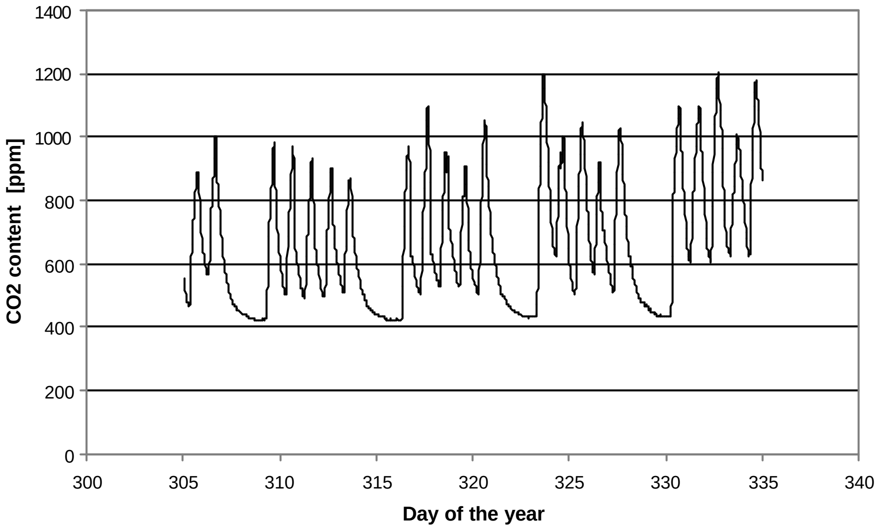

Figure 7. CO_2 content in the indoor air, November 2001.

4.3 Questionnaire

During two periods, summer and winter respectively, questionnaires have been conducted. The users were asked to evaluate a number of indoor climate parameters and also indicate the reason if not quite satisfied. The parameters were the room temperature, internal air movements, the air quality, the artificial lighting, the level of daylight and the noise level in the office. In addition the users were asked to evaluate the performance of the automatic control of the room temperature, the ventilation, the artificial lighting and the solar shading and also indicate to what extent they felt a need to regulate personally. Finally the users were asked if they had received information on how the automatic control of the technical installations operates and if so the quality of the information.

Just one brief example of the output from the questionnaires is given below. The figures 8 and 9 show the users evaluation of various indoor climate parameters in the winter situation and the summer situation, respectively. One obvious result is that the users are generally dissatisfied with the acoustic conditions in the office. As a consequence of the investigation the problem has been solved subsequently.

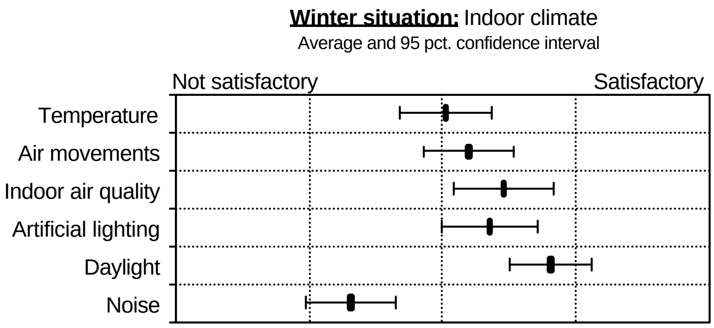

Figure 8. Summary of questionnaire for a winter situation.

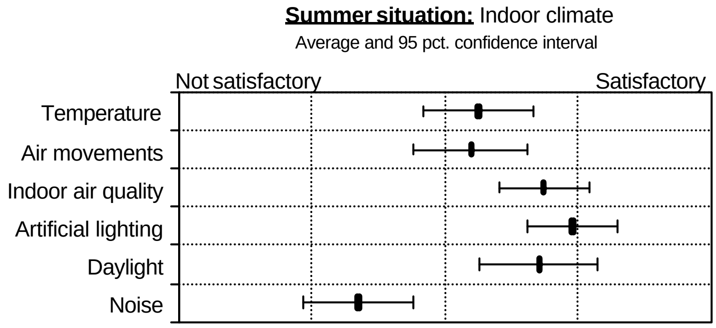

Figure 9. Summary of questionnaire for a summer situation.

5. CONCLUSIONS

The new Rockwool Research Centre has been designed for reaching an annual energy consumption for space heating of 1/3 of the Danish building code requirements. The constructions have been carefully chosen based on a life cycle analysis.

About one year of measurements have shown that, the energy goal set up in the design phase is hard to reach. The observed space heating demand is more than twice the target value, but however substantial lower than the building code requirements. The main reasons are a lower utilisation of the internal gains and solar gains than expected in the initial simulations and that the total U-values of the large glazing areas by detailed calculations are found to be closer to 1 W/m^2K than the 0.85 W/m^2K. The lesson learned is that design of low energy buildings requires a very detailed knowledge of the utilisation potential of solar gains and internal loads if the design values should be met in the real building. Also correct quantification of the thermal bridges even if they seems insignificant are extremely important.

The natural ventilation principle is performing as expected with respect to air change rates and resulting indoor air quality. However the summer 2001 showed an error in the night cooling strategy that never was activated and high indoor air temperatures are observed.

The users generally judge the indoor environment as positive except for the noise level in the open office environment. Measures are now taken to solve the problem.

6. REFERENCES

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