Study of the Energy Use Characteristics of Concrete Multi Family Dwelling Buildings and the Relevance for Economy and Environment

Mats Öberg
Ph.D. Student
Department of Building Materials
Lund University, Box 118, SE-221 00 Lund
E-mail: mats.oberg@cementa.se

ABSTRACT

Reduction of energy use in buildings is fundamental for sustainable development. A computer program for the prediction of energy use in buildings was assessed by comparisons with the energy performance of existing buildings. The program was then used to evaluate the energy saving characteristics of concrete such as air tightness and heat capacity.
The impacts on global environmental aspects and life cycle costs were examined. In a multi-family dwelling building a concrete building structure can contribute to a reduction of the annual requirement for space heating by up to 8%.

Key words: Energy use, Heat capacity, LCA, LCC, Thermal storage

1. INTRODUCTION

1.1 General

Representing 11% of the GNP and 40% of the total energy use within the EU [1], construction and operation of buildings has a large impact on economy and environment. The environmental council of the Swedish Building sector 'Byggsektorns Kretsloppsråd' [2] has established that energy required during the usage phase is the most critical environmental aspect for houses. The aspect of heating costs should also be considered. According to statistics for Swedish multi-dwelling buildings produced after 1986 this is in average 67 SEK/m^2 per year. [3] The significance of energy use implies that also relatively small differences regarding energy related characteristics within the built environment are important and that the prediction tools must be suited to appreciate this.

This is a study within the 'Optimal Concrete Building', a research project applying integrated life cycle design on multi-family dwelling buildings to explore the functional and economical advantages of concrete as building material.

1.2 Background

The potential energy demand for space heating and cooling of a building, at given outdoor climatic conditions and at a set interval of indoor temperature, depends on conductivity (transmission), convection (air movement through leaks) and radiation through the climate shell, ventilation rate and heat gains from people, equipment, lightning etc. The thermal inertia of a building can even out temperature fluctuations and thus reduce the required heating or cooling energy (thermal storage). The main thermal fluctuation cycle within a building is the twenty-four hour period. The energy saving potential of concrete buildings is related to their thermal mass, and in case concrete has the function of a vapour barrier in the climate shell also to air tightness. Concrete, however, has high thermal conductivity why careful design to avoid heat bridges is essential.

The impact of the thermal inertia depends on the effective heat capacity, that is the share of the total heat capacity that contributes to the heat exchange between component and indoor air during the fluctuation cycle. Furthermore, the indoor temperature must be allowed to fluctuate at least 2 to 3°C. Johannesson [4] modelled the heat balance of rooms including the effective heat capacity using the analogy with electrical resistances and capacitances, and finite difference equations for the calculations. The effective thickness of a 250 mm concrete wall or slab in contact with the room is 90 mm from the exposed surface, at a thermal transmittance of concrete of 1.2 $W/m^{2\circ}K$. In a field study Akander [5] has compared measured effective heat capacity and analytical results based on the principles defined by Johannesson and found adequate agreement.

Convection is driven by differences in air pressure over the climate shell, caused by wind or thermology (stack effect) and depends on the air tightness. In buildings with mechanical exhaust ventilation tightness has little influence on the energy requirement, as air leaks only substitute the fresh air taken in through valves. In the case of balanced or natural ventilation air leaks can correspond to between 10 and 30% of the heating energy requirement. In either case, air leaks affect the thermal comfort and may lead to moisture related problems within the climate shell.

In a review by Bergsten [6] on commercially available energy balance programs in Sweden in 2001, a total of 12 programs were accounted for, ranging from simple shareware tools, providing for crude estimations for single-family house applications, to customized versions of sophisticated university programs. Energy balance calculation programs can be grouped into dynamic and steady state. Steady state programs work in principle like hand calculations and their main advantage is that the computation effort is very small as they exclude complicated algorithms and the time resolution is at least a whole 24-hour period. The accurateness of a steady state program depends on the similarity between the specific conditions and those for which the calculation has been adapted. Such programs are therefore suitable for simple and standardised buildings, such as prefabricated single-family homes, where calibrations could be made based on the actual performance. The combined effect of, for instance, surplus energy, air leakage and thermal storage can thus be approximated but not calculated with a steady state program. The program mostly used in Sweden today, ENORM [7], is a steady state program that was developed at a time when the capacity of common PC-computers restricted the possibility to use dynamic programs. According to an analysis with this particular program on four multi family dwelling buildings by Adalberth [8] the actual energy use was underestimated by in average 27% and in a validation on 16 multi family dwelling buildings by Sandberg in 1998 [9] by as much as 50%. Besides the limitations with regard to the calculation method in steady state programs the large discrepancy can also be attributed to incorrect input data with regard to user behaviour and technical performance. For instance, there are approximated values for gain of solar energy and internal surplus heat based on experiences from houses built during the 60s and 70s that are not valid for the buildings currently produced. For general applications, such as multi-family dwelling buildings, dynamic programs are advisable. Currently there are several user-friendly dynamic programs available according to [6]. The European and ISO standard 'Thermal Performance of Buildings – Calculation of Energy Use for Heating' [10] employs the steady-state approach but the effect of thermal storage is quantified with a so called utilisation factor which is function of the heat loss, heat gains and the time constant of the particular building. The time constant is defined as the total effective heat capacity divided by the total heat loss by transmission, convection and ventilation. Akander [5] calculates the difference with regard to potential energy requirement in multi-family dwelling buildings with different thermal inertia with a dynamic energy balance calculation program and also with the above mentioned standard and concludes that the supplied energy for heating of the heavy building is 86-94% of the light building depending on the specific conditions.

Environmental goals defined by the Swedish Ministry of Housing and Planning for new dwelling buildings state that the total annual energy use should be limited to 90 kWh/m^2 per year in 2010 and further to 60 kWh/m^2 per year in 2020 [11]. Average annual energy use in currently produced multi-family dwelling buildings is 35 kWh/m^2 electricity and 140 kWh/m^2 space heating. For the development of more energy efficient buildings accurate prediction tools are essential.

1.3 Aim of the study

The aims of this study are as follows.

- To improve predictability of energy use for the operation of multi family dwelling buildings and to verify links between the building as well as heating and ventilation systems and the energy performance. This is a key to the improvement and optimisation of the building with regard to energy performance
- To evaluate the potential effect on energy performance in concrete buildings of selected parameters such as heat capacity, air tightness of the climate shell, heat bridges, indoor temperature and the ventilation system. In particular the interaction between building materials and ventilation system will be examined
- To evaluate the energy performance related effects on costs and global environmental aspects over the life cycle of the building

The underlying hypotheses are, firstly that a suitable program with proper input data can predict the energy performance with an accurateness of ± 10%, which is deemed to be sufficient. Secondly, that the effects on energy use with regard to heat capacity and air tightness of a concrete building frame and shell can be evaluated and that these effects have significance with regard to life cycle cost and global environmental aspects for residential buildings.

2. METHOD

The energy performance of an existing multi family dwelling building, over a period of one year, was mapped. This data was compared to results of calculations on the particular building made with an energy balance program employing the particular climatic conditions in order to assess the predictability of the energy balance of buildings. The program was then used to explore the effects on the potential energy use by differences with regard to building structure and ventilation system.

2.1 Case study on energy use in multi family dwelling buildings

A modern building with uncomplicated geometrical layout and ventilation and heating system was selected in order to focus on the comparison between calculated and real energy performance. It was one of eight similar two-floor blocks with eight flats each comprising a 520 m^2 net floor area, located in Svedala in the south of Sweden and owned by the semi-public company Bostads AB Svedalahem. See Figure 1. The building was completed in 1998.

Figure 1. Case study. 'Erlandsdal 1b'. Svedala.

The building frame was cast *in situ* on precast concrete floor plates see Figure 2, below. The exterior walls were clad with brickwork in a curtain wall of wood scantlings and insulation on the long sides and on insulation and concrete wall on the gables. Hot water radiators furnished by a natural gas boiler provide the space heating and the flats are equipped with mechanical exhaust ventilation.

Energy characteristics for the building over a period of one year (2000) were determined comprising charged energy for space heating, electricity used in the households and for general purposes in the building, ventilation rates and tap-water consumption. Indoor temperatures, number of inhabitants and airing frequenses were examined by a questionnaire on indoor climate developed by Engvall [12], that was used to evaluate the indoor climate which will be reported in another paper. Heat from persons was calculated by assuming that the occupants are inside their flats half of the time. The release of energy from one people was set to 60 W [13]. All electric energy used by the occupants inside their flats is regarded as gained within the energy balance whereas common electricity for ventilation fans and exterior lighting was excluded as the corresponding heat is generated outside the flats. Heating of hot water was estimated by the energy needed to increase the temperature of half of the tap water consumed during 2000 by 50°C.

2.2 Energy balance calculations

The program VIP+ [14] was used for the energy balance calculations. VIP+ is a dynamic program providing that can assess the impact of thermal inertia and air leaks. The program manages energy supply from space heating, solar radiation, internal gains (people, appliances) heat recovery from ventilation and energy release by transmission, ventilation, air leaks, hot water production and cooling. There are two specially designed calculation modules, one for the calculation of airflows through ventilation and air leaks according to Nylund [15] and one for heat capacity according to Johannesson [4].

The energy balance program was evaluated by calculating the energy requirement for space heating given the measured input data and comparing the results with the charged energy use for the specific year and then used to simulate the potential effects on energy use of different types of building frames and ventilation systems.

2.3 Evaluation of environmental and economical impacts of energy use

Environmental aspects
Emission factors from the particular energy sources including extraction and use: natural gas and electricity, were collected from a database for the computer program 'Life Cycle Inventory Tool' [16], see Table 1. Only the emissions addressed by the socio economic evaluation, described in Table 2, were selected. These emissions are deemed to be representative with regard to the most severe global ecological damages such as global warming, eutrophication, acidification and ozone depletion. Other substances also contribute to these damages but in the case of energy production these other emissions occur with good correlation to the chosen substances. Socio economic costs generated by the emissions according to the Swedish National Road Administration [17] are presented in Table 2. The socio economic cost principle was chosen because it operates with a unit that is directly comparable to the real costs.

Table 1. Emissions from different energy sources

Emission factors for selected energy sources (g/MJ)	CO_2	NOx	SO_2	VOC
Electricity. Swedish mix	12	0.02	0.01	0.003
Natural Gas	62	0.06	-	0.002

Table 2. Socio economic costs for emissions to air according to the Swedish National Road Administration

Socio economic cost SEK/kg	CO_2	NOx	SO_2	VOC
	0.015	60	20	30

Economy
Life cycle costs were calculated using a spread-sheet program developed for a study on life cycle costs in multi-family dwelling buildings. [18] The present value of annually recurring future events was calculated with the standard formula

$PV = P_n\, p/(1-(1+p)^{n})$ where (1)

P_n = cost for event at price level when it occurs
n = number of years until event occurs. Here: 60 years
p = discount rate

where p = real interest rate – annual increase of price above inflation
Here real interest rate 3.5 % (Average Swedish real interest rate 1960-2000) and increase of energy cost 0%, 3% or 6% above inflation.

3. RESULTS

3.1 Case study: energy use in a Swedish concrete multi family dwelling building

The use of energy and tap water during 2000 was obtained from Bostads AB Svedalahem and Sydkraft AB. In order to refine the evaluation of the program, quantifications on actual gains from persons and use of electricity were applied instead of available default values within the computer program. The indoor temperature, 22ºC, and the number of inhabitants, 16, were determined by a questionnaire. Table 3 displays the calculated energy balance and the charged energy for heating and it can be noted that reasonable coherence between calculated and charged energy use for heating has been achieved. Charged energy use was 144.5 kWh/m^2 which should be compared with the calculated 130.9 kWh/m^2 and is close to the accurateness pursued (± 10%). Error sources are related to the tenants behaviour but also to technical aspects such as the efficiency of the gas boiler that supplies the space heating and hot tap water and according to the manufacturer, Viessmann, is close to 1 or the stability of the ventilation system. Furthermore average climatic data were used for the calculations instead of data for the specific year.

Table 3. Case study: calculated energy balance (kWh/m^2)

Energy demand				Energy supply			
Transmission	Air leaks	Ventilation	Hot water	Solar radiation	Gains from electricity	Gains from persons	Heating
72.5	0.8	65.3	53.8	33.8	27.7	8.1	130.9

3.2 Potential influence of building materials and ventilation system on energy use

To study the effects of changes in the building frame, climate shell and ventilation system the original building frame of the case study (a) was compared with two alternative types according to Figure 2 and Table 4.

Table 4. Parametric study

Ventilation system/Type of building frame	Original	Heavy	Light
Mechanical exhaust. AL*=3, 64% of window area facing north	a1N		
Mechanical exhaust. AL*=3 **	a1	b1	c1
Balanced ventilation. AL*=3 **	a2	b2	c2
Balanced ventilation. AL*=1.5 in heavy structures, **	a3	b3	

* Air leakage through component at 50 Pa pressure difference measured in m^3/m^2,h
** 64% of window area facing south compare Annex A.

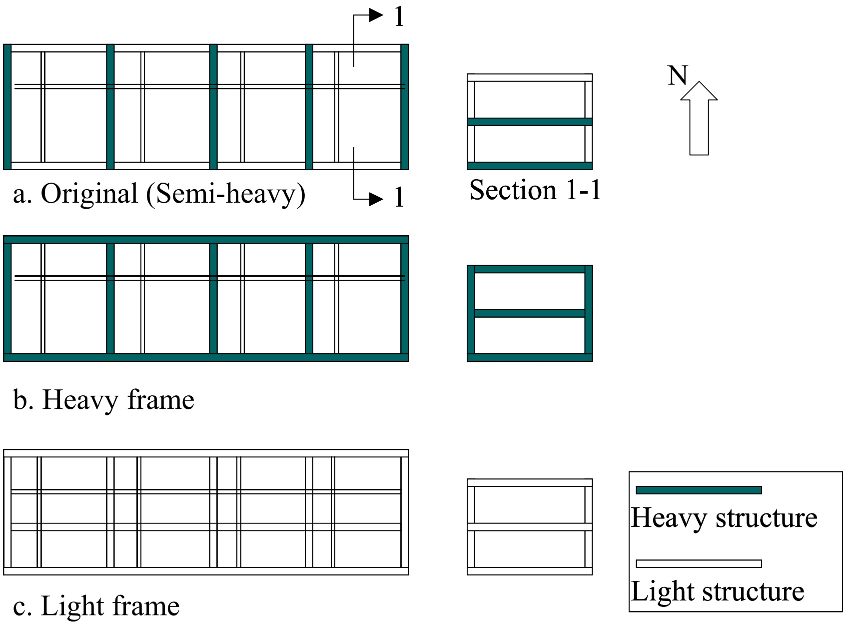

Figure 2. General layout of three different frames

For each case two different types of ventilation systems were studied: mechanical exhaust ventilation as in the original building and balanced ventilation with heat recovery. According to the orientation of the original building 64% of the window area faced directly to the north and 36 % to the south. An opposite distribution was used for the simulation of the impact of thermal inertia. Details on structures and energy related aspects are tabled in Annex A. Results of energy balance calculations are presented in Table 5, below and in detail in Annex B.

3.3 Impacts on energy use, economy and environment over the life cycle of the building

In table 5 the impact on annual costs, socio economic costs and present value of costs, at different increase of energy costs, for the alternatives examined within the parametric study are displayed. Note that performance of the cases of group 1 (mechanical exhaust ventilation) should not be directly compared with the results of group 2 (balanced ventilation with heat recovery).

Comparing the potential energy use the heavy building (b) requires about 95% of the bought energy for space heating of the light (c) structure due to thermal inertia. (Comparisons b1-c1 or b2-c2) This conforms with the results reported by Akander [5]. If differences in air tightness are taken into account the gap increases. The simulations indicate that from the annual cost perspective the impact of differences with regard to energy use between the alternative structures is small, 1 to 4 SEK/m^2 which should be viewed in relation to the average heating cost 67 SEK/m^2 in modern Swedish multi family dwelling buildings [3]. However with regard to life cycle costs, were the present value is a relevant indicator, the difference can be regarded as significant, ranging from 30 to 350 SEK/m^2 with regard only to thermal inertia and as much as 720 SEK/m^2 for the combined effect of thermal inertia and air tightness at an increase of energy cost of 3% above inflation. This can be compared with a typical production cost of a building frame of 3000-6000 SEK/m^2. The socio economic calculation show that there is an additional cost with regard to environmental aspects that is of the same magnitude as the straight cost.

Table 5. Energy use, Socio economic cost, annual cost and present value

Case*	Annual requirement of bought energy for space heating (kWh/m^2)	Annual Socio economic cost (SEK/m^2)	Annual Cost (SEK/m^2)	Present value. (SEK/m^2) Increase of energy cost more than inflation 0%	3%	6%
a1N	77.1	27	38	1066	2310	6697
a1	60.9	21	30	841	1824	5288
b1	59.6	21	30	825	1788	5184
c1	64.7	23	32	894	1938	5619
a2	40.2	14	20	556	1206	3496
b2	39.1	14	20	542	1176	3410
c2	43.5	15	22	603	1308	3792
a3	38.9	13	19	540	1170	3392
b3	33.8	12	17	468	1014	2940

* Cases according to table 4: a: original; b:heavy structure; c: light structure.

4. FURTHER WORK

The energy balance calculation program VIP+ will be further assessed by examining other existing multi family dwelling buildings. The air tightness of different types of exterior walls: light curtain walls, precast sandwich walls and cast in situ concrete walls, will be studied by field tests in existing buildings, to secure input data for calculations. The influence of concrete on the room temperature will be examined as that is an important indoor air quality aspect. Possibilities to reduce the required effect installed for space heating with regard to the thermal inertia will also be examined.

5. CONCLUSION

The two advantages of concrete with regard to energy savings; namely the heat capacity of the structures that are exposed to the indoor air and the possibility to obtain durable air tightness of the climate shell can contribute significantly to the life cycle performance of a building. This can be evaluated during the design phase by applying an adequate energy balance program and life cycle cost estimations. The effect with regard to global environmental aspects can be examined by a socio-economic calculation. The magnitude of the economical and ecological impacts motivates the application of this type of analysis to guide design decisions.

6. ACKNOWLEDGEMENTS

The author gratefully acknowledges the financial support of the Swedish Foundation for Strategic Research (SSF) and Cementa AB, as co-sponsor, for the project, "New research directions for the building sector", which forms part of the Swedish national graduate school and research program, *Competitive Building*.

The author gratefully acknowledges the assistance from Jörgen Grabo, Bostads AB Svedalahem, to aquire data for the case study.

REFERENCES

1. Sjöström, C., "Challenges of Sustainable Construction in the 21st Century," *Proceedings* RILEM/CIB/ISO Symposium on Integrated Life-Cycle Design, Helsinki 2000, Keynote lecture.
2. Byggsektorns Kretsloppsråd, "Byggsektorns betydande miljöaspekter," Miljöutredning för byggsektorn. Final Report. Stockholm, 2001, Sweden. (In Swedish)
3. Statistics Sweden, "Yearbook of Housing and Building Statistics 2000," Stockholm, Sweden, 2000.
4. Johannesson, G. "Active heat Capacity – Models and Parameters for Thermal performance of Buildings,". Report TVBH-1003. Lund University. Dep. of Building Physics, Sweden, 1981.
5. Akander, J. "Active heat Capacity – Models and Parameters for Thermal performance of Buildings,". Bulletin 180 Royal Institute of Technology. Dep. of Building Sciences, Stockholm, Sweden, 2000.
6. Bergsten, B. "Energiberäkningsprogram för byggnader" Report 2001:03. Effektiv CIT/SP/Chalmers. Gothenburg, Sweden, 2001 (In Swedish)
7. ENORM. Computer program for energy balance calculations. Energiforskning AB. Stockholm, Sweden
8. Adalbert, K., & Petersson, Ö., "Energy Use and Environmental Impact of new Residential Buildings" Report TVBH-1012. Lund University. Dep. of Building Physics, 2000, p 29.
9. Sandberg, E.,"Energimål – kort sikt, Hammarby Sjöstad". ATON Teknik Konsult AB, Stockholm, Sweden, 1998 (In Swedish)
10. EN ISO 13790. Thermal performance of buildings – Calculation of energy use for buildings. CEN. Brussel
11. Swedish Ministry of Housing and Planning, Boverket "God bebyggd miljö".Karskrona, Sweden, 1999 (In Swedish)
12. Engvall, K..Norrby, C, "Upplevt inomhusklimat i Stockholms bostadsbestånd," Report Nr 1992:4, Stockholms Stad. Utrednings och Statistikkontor, Stockholm., 1992, 40 (In Swedish)
13. Markus, T.A., Morris, E. N., "Buildings, Climate and Energy", Pitman Publishing Ltd., London, U.K.,1980, pp 42-43.
14. VIP+. Computer program for energy balance calculations. Skanska IT-Solutions. Stockholm, Sweden
15. Nylund,. P-O. Infiltration and Ventilation. Report D22:1980. Swedish Council for Building Research, Stockholm, Sweden, 1980. (In Swedish)
16. LCAiT. Computer program. Chalmers Industriteknik. Gothenburg, Sweden
17. Swedish National Road Administration, "Samhällsekonomiska Beräkningsförutsättningar," Vägverkets publikation 1999:170, Borlänge, Sweden, 1999, (In Swedish)
18. Johansson, C, Öberg, M, "Life Cycle Costs and Affordability Perspectives for Multi-Dwelling Buildings in Sweden," Proceedings 2nd Nordic Conference on Construction Economics and Organization, Gothenburg, Sweden, 2001, pp 287-297.

ANNEX A. Input data for energy calculations

Table A. Building structures. Areas and energy related data

Structure	Type	Area	U-value	Air leakage	Glass share/ Transmittance
a1N		m^2	$W/m^{2o}C$	m^3/m^2,h	%
Wall North	Light	125.5	0.194	3	
Wall South	Light	157.0	0.194	3	
Wall East.	Concrete	48.0	0.194	3	
Wall West	Concrete	48.0	0.194	3	
Window North		15.7	1.50	3	70/80
Window South		47.2	1.50	3	70/80
Glas door North		16.9	1.50	3	45/80
Door South		16.9	1.50	3	
Roof, Light		260.3	0.116	3	
Floor on ground	Concrete	224.3	0.234		
Floor on ground	Concrete	36.0	0.360		
Inner wall	Concrete	98.0			
Inner wall	Light	150.0			
Inner floor	Concrete	260.3			
a1, a2, a3		m^2	$W/m^{2o}C$	m^3/m^2,h	%
Wall South	Light	125.5	0.194	3	
Wall North	Light	157.0	0.194	3	
Wall East	Concrete	48.0	0.194	3. In a3: 1,5	
Wall West	Concrete	48.0	0.194	3. In a3: 1,5	
Window South		15.7	1.50	3	70/80
Window North		47.2	1.50	3	70/80
Glas door South		16.9	1.50	3	70/80
Door North		16.9	1.50	3	
The rest like a1N					
b1, b2, b3		m^2	$W/m^{2o}C$	m^3/m^2,h	%
Wall. North	Concrete	125.5	0.194	3. In b3: 1,5	
Wall South	Concrete	157.0	0.194	3. In b3: 1,5	
Wall.East	Concrete	48.0	0.194	3. In b3: 1,5	
Wall West	Concrete	48.0	0.194	3. In b3: 1,5	
Roof	Concrete	260.3	0.116	3. In b3: 1,5	
The rest like a1					
c1, c2		m^2	$W/m^{2o}C$	m^3/m^2,h	%
Wall.East	Light	48.0	0.194	3	
Wall West	Light	48.0	0.194	3	
Inner wall	Light	248.0	0.116	3	
Inner floor	Light	260.3			
The rest like a1					

ANNEX B. Energy calculations. Results

Table B. Calculated energy balance. (kWh/m^2)

	Trans-mission	Air leaks	Ventilation	Excess* ventilation	Heat recovery.	Solar gains	Internal gains	Heating **
a1N	72.5	0.8	65.3	7.0	-	33.8	34.8	77.1
a1	76.8	0.8	67.0	14.2	-	63.3	34.8	60.9
b1	76.8	0.8	67.0	12.7	-	63.3	34.8	59.6
c1	76.6	0.9	66.8	18.5	-	63.3	34.8	64.7
a2	79.8	17.1	60.6	16.9	36.9	63.3	34.8	40.2
b2	79.9	17.1	60.7	15.3	36.7	63.3	34.8	39.1
c2	79.2	17.2	60.3	21.2	37.0	63.3	34.8	43.5
a3	80.0	15.3	60.8	17.1	36.9	63.3	34.8	38.9
b3	80.7	9.4	61.2	16.5	36.9	63.3	34.8	33.8

* Ventilation due to exceeded maximum indoor temperature (28°C), **Hot tap water production excluded