Building Simulation 2003

Eighth International IBPSA Conference
Eindhoven, Netherlands
August 11-14, 2003

HEATING ENERGY USE SIMULATION FOR RESIDENTIAL BUILDINGS

Jerry Sjösten, Thomas Olofsson and Mohammad Golriz

Department of Applied Physics and Electronics
Umeå University, Sweden

ABSTRACT

In this paper, we present a new simulation program, TEKLA, for estimating energy use of residential buildings according to the European standard, EN832. The simulation program is written in MATLAB 6.2. The focus is to estimate variations of significant parameters influencing the energy use of the building. TEKLA can be used in design of new and retrofitted energy-efficient buildings. The model predictions are in good agreement with monitored data from an occupied residential building located in Umeå in northern Sweden.

KEYWORDS

Building, Energy Efficiency, EN 832, Simulation.

INTRODUCTION

The residential and tertiary sectors have been shown to be the largest overall end users (40.7% of total energy use), mainly for heating, lighting, appliances and equipment. Numerous studies and practical experience show that there is a large potential for energy savings here, probably larger than in any other sector (EU, 2001a). Procedures for identifying energy efficiency in buildings are becoming increasingly important after the statement of the EU Commission proposing measures to promote energy efficiency of buildings (EU, 2001b).

In the process to find procedures to identify energy efficient buildings it is important to notice that there is no guarantee that a low energy occupied building is energy efficient. It can be low energy just because of the occupation schedules, low amenities, etc. The same contradictions can be found for energy efficient buildings not being low energy. The efficiency equipment may not be appropriate installed to reduce the most adequate energy using loads. The more appraisals are high-energy buildings with good efficiency that would be very energy consuming without the efficiency equipment. An efficient building must contain elements from three categories Meier et al. (2002). The first element is that buildings must supply the amenities and features appropriate for that kind of building. The second is that the building must be a low energy building, which means that the building must be operated in such a manner as to be efficient. The third element is that the building must be energy efficient. It means that the building must contain energy-efficient technologies and design that, when operating as designed, will effectively reduce energy use.

The last element including energy-efficient technologies and design can be evaluated based on a sensitivity analysis of the contribution to the heating energy use based on expected major sources. In this paper we introduce a computer simulation tool called TEKLA, which is developed to obtain such analyses. An evaluation of the tool is obtained based on data from a monitored inhabited single-family building.

THE TEKLA SIMULATION MODEL

The TEKLA simulation model is based on the calculation procedure given in EN 832 (1998) and the program is written in MATLAB 6.2. The implemented model is improved for calculation of the energy use of an occupied residential building in cold and mild climate, and the chosen calculation periods. This means that all parts of the EN 832 calculation procedure are not implemented. In the following, the model is presented and compared with measured use of energy of an available monitored and documented occupied residential building in Umeå, the reference building.

The Calculation Model

The implemented model is based on the thermal properties of the building, average values of a studied time period of the interior and exterior temperature, ventilation airflow, and heat loss through the floor/slab, $\dot{Q}_{floor}$. The total heat loss, Q_l, is calculated according to

$$Q_l = \left(H(\theta_i - \theta_e) + \dot{Q}_{floor}\right)t \qquad (1)$$

where H, $\theta_{i,}$, θ_e and t, are the heat loss coefficient of the building (except the floor), the average interior temperature, the average exterior temperature and the duration of the calculation period, respectively.

The calculation of the heated space is not based on different thermal zones. The set-point for the interior temperature is the same for the entire heated building volume. The effects of intermittence of the interior temperature are not considered. Based on the measurements of the building that assumption was in good agreement with actual conditions and will the accuracy will be only slightly affected.

The set-point for the interior temperature is taken as the monthly average measured interior temperature and the exterior temperature is the average for the calculation period of the measured exterior temperature.

The heat loss through the floor is calculated using the procedure given in EN ISO 13 370 (1998).

The calculation of H comprises

$$H = \sum U_i A_i + \rho_a C_a \dot{V}(1 - \eta_{ven.rec}) \quad (2)$$

where U_i, A_i, $\dot{V}$, ρ_a, C_a and $\eta_{ven.rec}$ are the thermal transmittance (U-value) of the building component, the area of the building component, the ventilation airflow, the density of air, the heat capacity of air and the efficiency of ventilation heat recovery device, respectively.

A procedure for calculation of the ventilation heat loss for buildings with balanced mechanical ventilation systems, with a supply and exhaust air systems and infiltration, is implemented in the program. The efficiency factor $\eta_{ven.rec}$ is only introduced here to show how it is used in the simulations.

The total internal heat gains, Q_g, has been determined as the sum of the measured energy use for appliances and lighting, Q_{app}, 20% (according to Olofsson, 2000) of the measured energy use for domestic hot water preparation, Q_{hw}, and the metabolic heat gains, Q_m, based on estimated daily average dissipation of heat from occupants. The solar heat gain for the used calculation period, $Q_{s,}$ was calculated using the commercial energy simulation software ENORM 1000. The total heat gain can thus be written

$$Q_g = Q_m + 0.2 Q_{hw} + Q_{app} + Q_s \quad (3)$$

The calculated total heat loss and total heat gain are then used to obtain the space heating use, $Q_{h,}$ for the calculation period

$$Q_h = Q_l - \eta_{uti}\, Q_g \quad (4)$$

where Q_l is the total heat loss of the building and the utilization factor, η_{uti}, which is a measure of how much of the heat gain that can be utilized in order to reduce the energy needed for space heating.

The used η_{uti} depends on the ratio between the total heat gain and the total heat loss of the building, the time constant of the building, and if the calculation period is a month or the whole heating season according to

$$\eta_{uti} = \frac{1 - \gamma^a}{1 - \gamma^{a+1}} \qquad \text{if } \gamma \neq 1 \quad (5)$$

$$\eta_{uti} = \frac{a}{a + 1} \qquad \text{if } \gamma = 1 \quad (6)$$

where

$$\gamma = \frac{Q_g}{Q_l} \quad (7)$$

$$a = a_0 + \frac{\tau}{\tau_0} \quad (8)$$

where τ is the time constant of the building.

The numerical values of the reference time constant τ_0 is 16 and a_0 is 1 for monthly calculation periods and 28 and 0.8, respectively, for seasonal heating periods.

Evaluation of the TEKLA Simulation Program

The results from the model prediction were compared with data of the reference building. It was a single-family building that was monitored during the time period 1995 to 1996 (Olofsson, 1997). The building was an inhabited single story row house, built in 1974 and located in Umeå (700 km north of Stockholm, Sweden). The building was ventilated by a mechanical exhaust fan and was not equipped with heat recovery ventilation system. The space heater and domestic hot water heater were both electric. The framework was made of wood, and the walls were insulated with 0.12 m mineral wool and the roof with 0.18 m. All windows were double-glazed with a double window frame. Further information about the building performance can be found in Jonsson and Östin (1992).

The properties of the reference building are shown in Table 1. These properties encompass the documentation is Jonsson and Östin (1992) except for windows. Those U-values deviated from of the estimated U-value of the windows based on EN ISO 10 077-1 (2000) and a model introduced by Kreider and Rabl (1994).

Table 1. *Properties of the reference building.*

Building component	U-value, W/m^2 K	Area, m^2
Windows	2.60	20.2
Roof	0.24	137.0
Doors	2.00	4.7
Walls	0.37	91.3

The last two calculation procedures gave a mean U-value of 2.45 W/m^2 K. The total U-value for the same sort of window was 2.6 W/m^2 K according to manufacturer data. The difference of 0.15 W/m^2 K could be explained by deteriorating affects (e.g. thermal bridges).

The average exchanged airflow in the exhaust air duct, based on measurements, was estimated to 49 l/s for the investigated periods and this was assumed to be the total airflow to be heated (including air infiltration).

For the simulation, the measured interior and exterior temperatures and energy use for space heating, domestic hot water preparation, and domestic appliances originates from February and March 1996. That was due to the quality of the data (gap free). The calculated energy use for February was 3.6 MWh and the corresponding measured use of energy for space heating was 3.1 MWh. Thus, the model overestimates the energy use with 15%. When the calculation was carried out for March the calculated and measured use of energy for space heating was 2.6 MWh and 2.3 MWh, respectively, i.e. an overestimation of 12%.

Arguments for uncertainty analyses for improving energy efficiency can easily be found. Petersen (1994) concluded that an uncertainty of ±15% of the average heating energy use for residential buildings is due to uncertainties in the building construction. That estimation gives a hint of the need for careful documentation as well as major savings from optimized design. A large number of energy sensitivity analysis methods have lately been introduced, and a comprehensive overview of previous works in this field is given in de Wit (2001). Properties of the reference building are originated from the construction of the building. In order to reduce the energy use an extra insulation in the roof is a common traditional measure of house owners in Sweden. The calculated use of energy for February and March 1996 was 3.2 MWh and 2.3 MWh, respectively, when an additional insulation of 0.20 m was added to the roof construction according to the original blueprints. After that change had been considered in the calculations of the reference building the corresponding deviation between calculated and measured energy use for space heating were 2.4% and 1.0%, respectively.

RESULTS AND DISCUSSION

In this study TEKLA has been used for conducting monthly calculations of the energy use for space heating based on properties given in Table 1, called reference building. The energy use for domestic hot water preparation, the sum of energy use for appliances and lighting, and the climate data for February 1996, in Umeå were taken from the measurements. Influence of various parameters on the energy use can be investigated. A sensitivity analyses indicates that U-values of wall, roof, and windows, and air change rate have a significant effect on the thermal performance of the building. This is reported by other researchers, e.g. Jamieson (2002) and Dilmac and Kensen (2003) among others. In climates with a significant heating season, windows have represented a major source of unwanted heat loss, discomfort, and condensation problems. It should be pointed out that heat loss due to windows represents approximately 2.3% of the Swedish national energy use. Thus, efficient windows can drastically reduce this energy use.

Dilmac and Kensen (2003) concluded that the air change rate had less influence than the other parameters. The reason for this may be explained by the difference in climate as Dilmac and Kensen (2003) made their investigation in Turkey. Another reason for this could be that the Swedish buildings are built to such high standards that uncontrolled infiltration rates around 0.1 air changes per hour; mechanical ventilation supplies an amount of outdoor air closer to the right amount, Kreider and Rabl (1994). Using air-to-air heat exchanger can minimize the energy consumption significantly. Except for building components the sensitivity analysis of energy use can also be based on building form, Oral and Yilmaz (2003). In this study we illustrate the effect of three common used refurbishment measures on energy use for the reference building, namely:

- Roof insulation thickness
- Window U-value
- Ventilation heat recovery efficiency

The reason for this, in addition to the above mentioned, is the possibility of modifying these properties of an existing building without extensive reconstruction.

Figure 1 shows the ratio of the calculated use of energy ($Q_{h,calc}$) and the calculated use of energy for the reference building ($Q_{h,0}$) as a function of the roof insulation thickness. $Q_{h,0}$ has been calculated based on the properties given in Table 1. Improvement potentials for the reference building are illustrated as the gradient of the use of energy curve. The results indicate that an increment of the insulation thickness of 0.2 m at an insulation thickness of 0.18 m reduces the use of energy about 11%, while the same action at an insulation thickness of 0.4 m gives a reduction of about 3%. Figure 1 also illustrates the utilization factor. We can see that the total energy use decreases with increasing roof insulation thickness despite the utilized heat gain decreases.

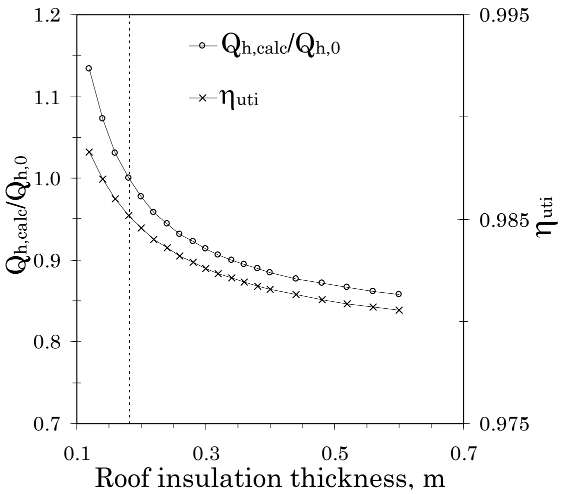

Figure 1. *The ratio $Q_{h,calc}/Q_{h,0}$ as a function of the roof insulation thickness. The dashed line indicates the reference roof insulation thickness (0.18 m). $Q_{h,0}$ = 3.6 MWh.*

The ratio $Q_{h,calc}/Q_{h,0}$ as a function of the U-value of the windows is presented in Figure 2. As expected the energy use decreases approximately linearly with decreasing U-value of the window. The type of windows is an important element in limiting the heat losses as shown in Figure 2. The U-value of the reference building is high compared with other types of windows in the market that indicates there is large potential for reducing the total energy use. In case of replacing the windows with low emissivity double glazing ones (U = 1.75 W/m^2 K) saving up to 10% of space heating costs.

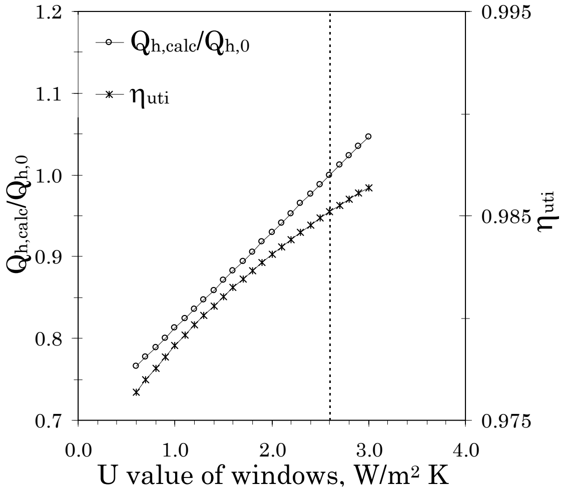

Figure 2. *The ratio $Q_{h,calc}/Q_{h,0}$ as a function of the U value of the windows. The dashed line indicates the reference U-value of windows (2.6 W/m^2 K). $Q_{h,0}$ = 3.6 MWh.*

Figure 3 illustrates the ratio $Q_{h,calc}/Q_{h,0}$ as a function of the efficiency of the heat recovery device. The reference building is not equipped with a ventilation heat recovery device. The results indicates that a reduction of the energy use for space heating of 10% is possible to achieve if a ventilation heat recovery device with an efficiency of 30% is used.

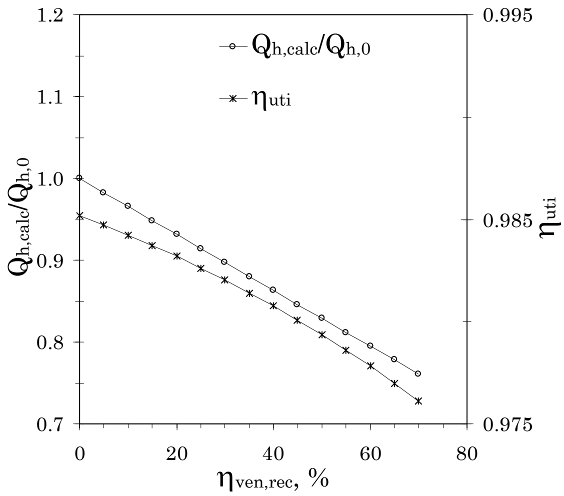

Figure 3. *The ratio $Q_{h,calc}/Q_{h,0}$ as a function the efficiency of the ventilation heat recovery device. $\eta_{ven,rec}$ = 0% for the reference building. $Q_{h,0}$ = 3.6 MWh.*

When actions aiming to reduce the use of energy are considered it is important to estimate the status of the improvement potential of the building components. Figures 1 to 3 provide status estimations of the chosen building parameters for the reference building. For example if the roof insulation thickness is considered, the gradient of the use of energy curve in Figure 1 gives useful information about the exchange of a taken action.

Furthermore, the variation of the utilisation factor is also presented in Figures 1 to 3 in order to show how the utilisation of the heat gains changes when the investigated parameters are varied. Due to the occurrence of the heat gains and the possibility of the building construction to store energy, it is not possible to use all heat gains to reduce the use of energy for space heating, Weber (2002).

CONCLUDING REMARKS

The European Standard EN 832 is implemented in a computer program in MATLAB 6.2. The model predictions are in good agreement with monitored data from an occupied residential building in cold and mild climate.

The simulation program, TEKLA, can be an aid for decisions of an energy efficient building design in the design stage as well as for refurbishment. The sensitivity analysis illustrates the expected energy use savings that can be obtained from alternatives of building component. That can be useful in the work to apply the EU Commission proposal to promote and certification of energy efficiency of buildings.

On the basis of the TEKLA model predictions various energy saving measures can be evaluated. The model optimizes the design on a technical level. In the future, economical as well as environmental measures will be included in the program in order to extend the usefulness of the TEKLA simulation model.

ACKNOWLEDGEMENT

The authors like to express their gratitude to Ms. Maria Boman for her support in the development of the MATLAB model.

NOMENCLATURE

A_i	area of the building component, [m^2]
a_0	constant in Eq. (8). It is 1 for monthly calculation periods and 0.8 for seasonal heating periods, [-]
C_a	heat capacity of air, [J/kg K]
H	heat loss coefficient of the building, except the floor, [W/K]
Q_{app}	sum of the measured energy use for appliances and lighting, [kWh]
$\dot{Q}_{floor}$	average heat loss through the floor, [W]
Q_g	total internal energy heat gains, [kWh]
Q_h	total space heating use, [kWh]
Q_{hw}	energy use for domestic hot water preparation, [kWh]
Q_l	total heat loss of the building, [kWh]
Q_m	metabolic heat gains from occupants, [kWh]
Q_s	solar heat gain, [kWh]
t	duration of calculation period, [h]
U_i	thermal transmittance (U-value) of the building component, [W/m^2 K]
$\dot{V}$	ventilation airflow to be heated, [m^3/s]

Greek letters

γ	ratio of Q_g / Q_l, [-]
η_{uti}	measure of how much of the heat gain that can be utilized, [-]
$\eta_{ven.rec}$	efficiency of ventilation heat recovery device, [-]
θ_e	average exterior temperature, [°C]
θ_i	average interior temperature, [°C]
ρ_a	density of air, [kg/m^3]
τ	time constant of the building, [h]
τ_0	reference time constant in Eq. (8). It is 16 for monthly calculation periods and 28 for seasonal heating periods, [h]

REFERENCES

de Wit, S., and Augenbroe, G. (2002), *Uncertainty Analysis of Building Design Evaluations*, Proc. Building Simulation 2001, 7th Int. IBPSA Conference, August 13-15, Rio de Janeiro, Brazil.

Dilmac, S., and Kesen, N. (2003), *A Comparison of New Turkish Thermal Insulation Standard (TS 825), ISO 9164, EN 832 and German Regulation*, Energy and Buildings, vol. 35, pp. 161-174.

ENORM 1000 (1996), Version 1.01, Svensk Byggtjänst Förlag, Stockholm (in Swedish).

EU (2001 a), Council of the EU, *Directive of the European Parliament and of the Council- on the Energy Performance of Buildings*: 2001/0098 (COD).

EU (2001 b), Council of the EU, Interinstitutional file: 2001/0090 (COD).

European Standard EN 832 (1998), *Thermal performance of buildings - Calculation of energy use for heating - Residential buildings*, European Committee for Standardization, Brussels, Belgium.

European Standard EN ISO 10 077-1 (2000), *Thermal performance of windows, doors and shutters - Calculation of thermal transmittance – Part 1:*

Simplified method, European Committee for Standardization, Brussels, Belgium.

International Standard ISO 13 370 (1998), *Thermal performance of buildings - Heat transfer via the ground - Calculation methods,* International Organization for Standardization, Geneva, Switzerland.

Jamieson, V. (2002), *Energy Savings Go through the Roof*, Physics World, Special Issue, Energy Challenges for the 21th Century, 15 No. 7, pp. 32-32.

Jonson, J. Å., and Östin, R. (1992), *Eleffektiva småhus i Umeå*, Report 871006-8, 890802-5, Swedish Council for Building Research (in Swedish).

Kreider, J. F., and Rabl, A. (1994), *Heating and Cooling of Buildings – Design for Efficiency*, McGraw-Hill, Singapore, ISBN 0-07-113438-7.

Meier, A., Olofsson, T., and Lamberts, R. (2002), *What is an Energy-Efficient Building?*, Proceedings of the ENTAC 2002 - IX Meeting of Technology in the Built Environment, Foz do Iguaçu, Brazil.

Olofsson, T. (1997), *Building Energy Load Predictions*, Department of Applied Physics and Electronics, Umeå University, (Licentiate Thesis) ISBN 91-7191-358-0.

Olofsson, T. (2000), *Energy Models for Single-Family Buildings*, Department of Applied Physics and Electronics, Umeå University, (Ph.D. Thesis) ISBN 91-7191-827-2.

Oral, G. K., and Yilmaz, Z. (2003), *Building Form for Cold Climatic Zones Related to Building Envelope from Heating Energy Conservation Point of View*, Energy and Buildings, vol. 35, pp. 383-388.

Pettersen, T. D. (1994), *Variation of Energy Consumption in Dwellings Due to Climate, Building and Inhabitants*, Energy and Buildings, vol. 21, pp. 209-218.

Weber, T. (2002), *Low-energy Houses - Visions ad Reality - A Statistical Survey on Real Energy Consumption in 400 Swedish and German Houses*, BULLERTIN NO 190, Byggnadsteknik, Kungliga Tekniska Högskolan, Stockholm, (Licentiate Thesis) ISSN 0346-5918.