THE USE OF A SIMPLE SIMULATION TOOL FOR ENERGY ANALYSIS

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ABSTRACT

The purpose of this paper is to present a new method to energy analysis. The method consist three different phases: in the first phase the target values of energy consumption are determined. In the second phase the potential differences between target and measured consumption are inspected by auditing the building. The effect of different energy saving measures are analysed in third phase. All these phases are assisted with a simulation tool. This tool uses effectively data base for generating input values for calculations. Minimum information need is the year of construction and type, location and volume of the building. During the audit the input values are checked and supplemented. The tool consist also semi-automatic procedures for fault diagnosis and energy saving measures. The calculation method itself is now quite simple and based on steady-state method.

INTRODUCTION

The rapid development of computers has during the recent years continued. However, broad application of simulation software in the building and HVAC design industry remains yet to be seen. Maybe to reason for that is the trend to develop more detailed programs which are not enough user-friendly for normal users like design engineers or maintenance persons.

Also the user of these detailed programs have to know and feed lot of details which sometimes are not known or are very expensive to clarify. Whole this process takes lot of time and leads high charges. Also user of these programs have to be quite experienced.

There is need to carry out calculation quickly and easy with a few parameter. For example during early design stages there is need to analyse the energy economy of the building when plans are unaccomplished e.g. structures, orientation, air flows, systems, equipment heat gain and operation time are nor chosen or known. The main information need in this phase is only find guidelines for detailed analysis. In practice these analysis are not carried out.

During maintenance work it is important to know target values of energy consumption and analyse the function of buildings. However, typically calculated and fixed values for individual buildings are not used. The measured consumption of previous year is normally used as a reference value in monitoring. The problem of most programs is to produce target values easy and cheaply when only the basic information of building is known. Normally most of sophisticated programs are too clumsy and maybe too versatile to give target values of monthly heating and electricity consumption.

ENERGY SAVING POTENTIAL

Technically speaking the building sector offers a huge potential for energy analysis. In the OECD countries the building sector accounts for about 30 % of the total consumption of energy. In Finland the importance of building sector is even higher: building sector accounts about 40 % of the total consumption. Between years 1992-95 many Finnish municipalities and private enterprises have made an agreement with the Ministry of Trade and Industry on objectives and measures for energy saving.

The City of Helsinki is one participant who has made this kind of energy saving agreement. The agreement presumed that the City would save, by 1996, 3,5 % of the heat consumption and 5 % of the electricity consumption of its own buildings. The objectives for 2005 are 10 % and 15 %, respectively. The base year is 1990. Financially, in the City of Helsinki the expected savings are FIM 12 million and FIM 30 million for the years in question (1 US $ equals FIM 4,64 based on the exchange rate of December 20, 1996) (Kosonen 1994).

The City of Helsinki has agreed to examine and put into practice new savings goals, to improve their follow up, and to develop new economical technologies together with the Ministry. The Ministry has agreed to participate in the financing of research and the implementation of the energy conservation projects.

Energy audits has been carried out in 98 buildings owned by the City. The results showed that the potential savings for these buildings would be, on average, 17 % in heating energy, 9 % in electricity, and 7 % in water consumption. In one year, the savings would amount to FIM 3 million, and the required investments would be paid back in 1.5 years. The audits are continuing and will be carried out altogether on 150 buildings by the end of 1996.

PROCESS OF ENERGY ANALYSIS

The general scope of energy analysis is to analyse the heating and electrical energy consumption, determine the targets of energy use and present economical energy saving measures.

Developed energy analysis consists three phases: (1) office, (2) audit and (3) analysis phase. In the office phase background information on the building is collected and reference value of consumption is calculated only with few basic parameters of the building. Minimum information need of the calculation is the year of construction and type, location and volume of building. (Note: In practise it is difficult of obtaining the required all needed input values for detailed calculations. This is especially the case for older buildings, with inadequate and possible out-of-date design documents.)

Calculated reference value of energy consumption is in key role when buildings are chosen to energy audit. The difference between calculated and measured values always indicates that there is something exceptional in the studied building.

Logical reasons for abnormal consumption are:

- inappropriate use of systems (operation times or set points),
- faults in systems (e.g. heat recovery and controls),
- high heat gains (solar or equipment),
- abnormal use of domestic hot water or
- wrong input data in target calculation (e.g. operation time of building has changed or technical data of systems or structures is wrong).

In the audit phase the building and technical systems are inspected and the reason for difference is tried to discover. Some cases measurements are needed to carry out. With collected detailed information of the studied building in the analysis phase the new target value for energy consumption is calculated. This specified value is used in monitoring of the operation of studied building.

Also in the analysis phase the measures which improve the energy economy and indoor conditions are studied. The profitable measures are presented.

The calculation steps and whole process is illustrated in figure 1. It should be noticed that calculated target could be also higher than measured consumption. This indicates typically too low ventilation rates and there maybe problems in indoor climate.

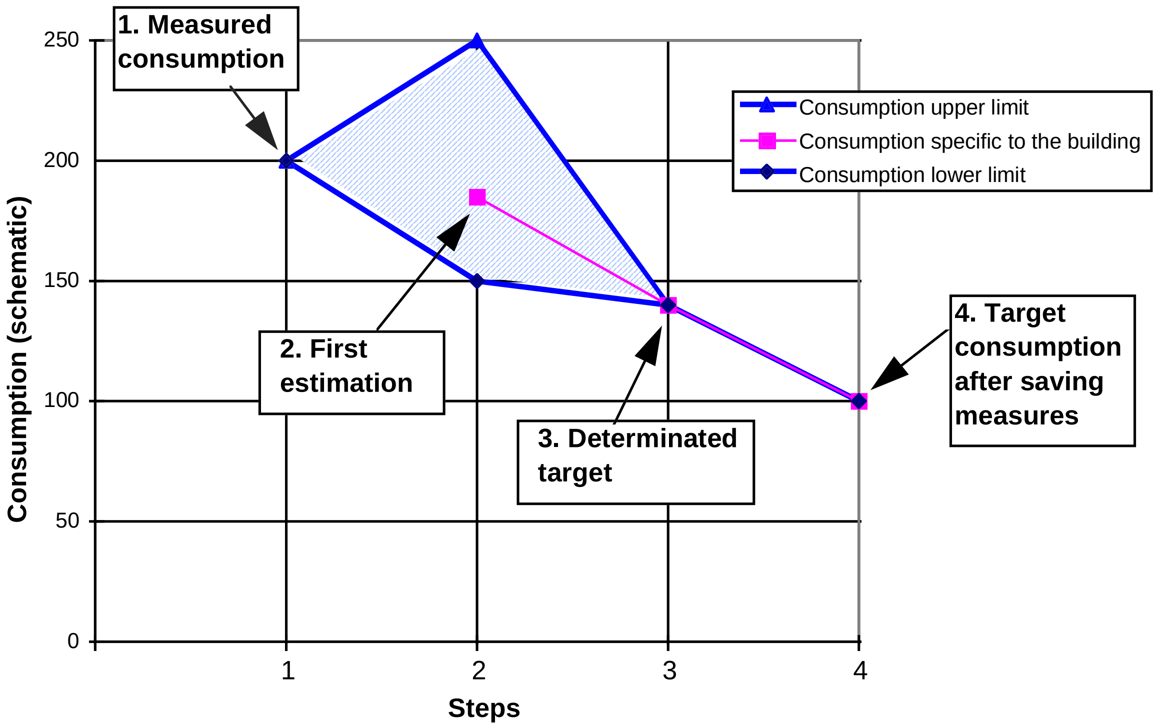

Figure 1. The calculation steps and process of energy analysis. (1) measured consumption, (2) first estimation of target consumption (3) determinated target for energy consumption (4) target consumption after energy saving measures.

APPROACH TO SIMULATION

When the accuracy of simulation is considered, the effect of input parameters and calculation method have to be considered separately. In a normal case when basic information is unknown, as it is situation when the first target consumption is calculated in energy analysis, the chosen input values effect more than calculation method itself to reliability. Figure 2 illustrates the relative importance of input values and calculation method to reliability in three hypothetical cases.

For determinating targets to monthly and annual heating energy consumption, quite a simple steady-state-method is adequate in most cases. Being a steady state method it of course has several limitations. For example when thermal mass of building is significant, e.g. as it is when the heating demand is rather low compared to heat gain (solar and equipment), results of steady state model are nor reliability.

All in all here is wanted to emphasise the importance of input values. In the energy analysis process the calculation tool does not even need to be accurate to the n:th decimal.

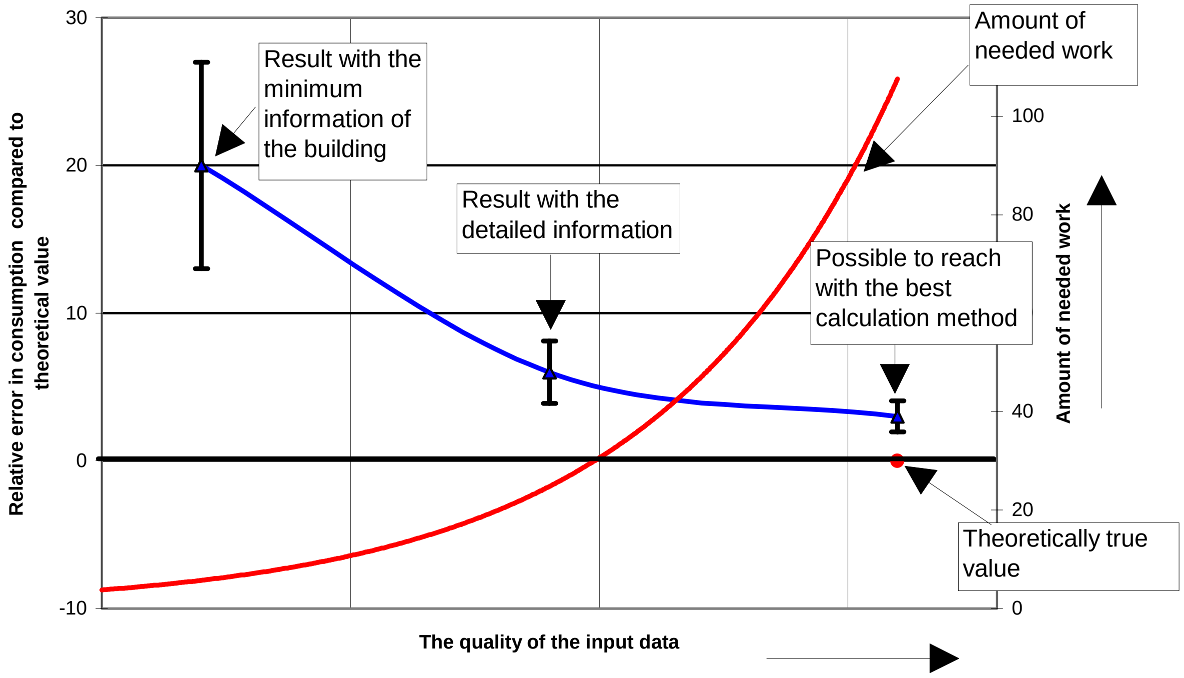

Figure 2. Relative importance of input values / different assumptions and calculation method when the target values for heating energy consumption are determined in three hypothetical cases.

THE WINETANA PROGRAM

The calculation program is designed so, that the input data can be specified step by step according to the information known.

Main idea of the program is, in the first phase, to know some minimum information about the building. With this minimum information, the first value of the target energy consumption can be calculated. Most of the input data, that calculation needs, is located in a knowledge data base, from where it is collected during the first calculation (Figure 3).

Program makes "intelligent" assumptions for the building during the first calculation. The assumptions are based on the building type, location, construction year and the geometrical information of the building (volume, shape of the building, number of floors, floor height). Program gets the U-values, window-types, water consumptions, electricity consumptions, internal gains from the data base and calculates the areas for the envelope.

All generated input values can be changed after the assumptions, if they are known better.

Intelligent assumptions and the knowledge base are fixed for Finnish buildings only, because the building regulations, construction types, water consumptions and so on vary between different countries.

WinEtana program environment consists of several parts (Figure 3.):

- Data base for the input values (collected by the year of construction and the building type).
- The program interface and the input data generator. This contains the "Finnish fixed" knowledge base.
- The stedy state model for calculating the monthly energy balance in building.
- Semi-automatical analysis tools:
  - ⇒ Possibility to explain automatically the differences between the measured and calculated energy consumption with some major loss components.
  - ⇒ Possibility to calculate some energy saving measures (changing the U-value of walls, windows, installing a heat recovery unit and so on) and the financial profitability of the investment.

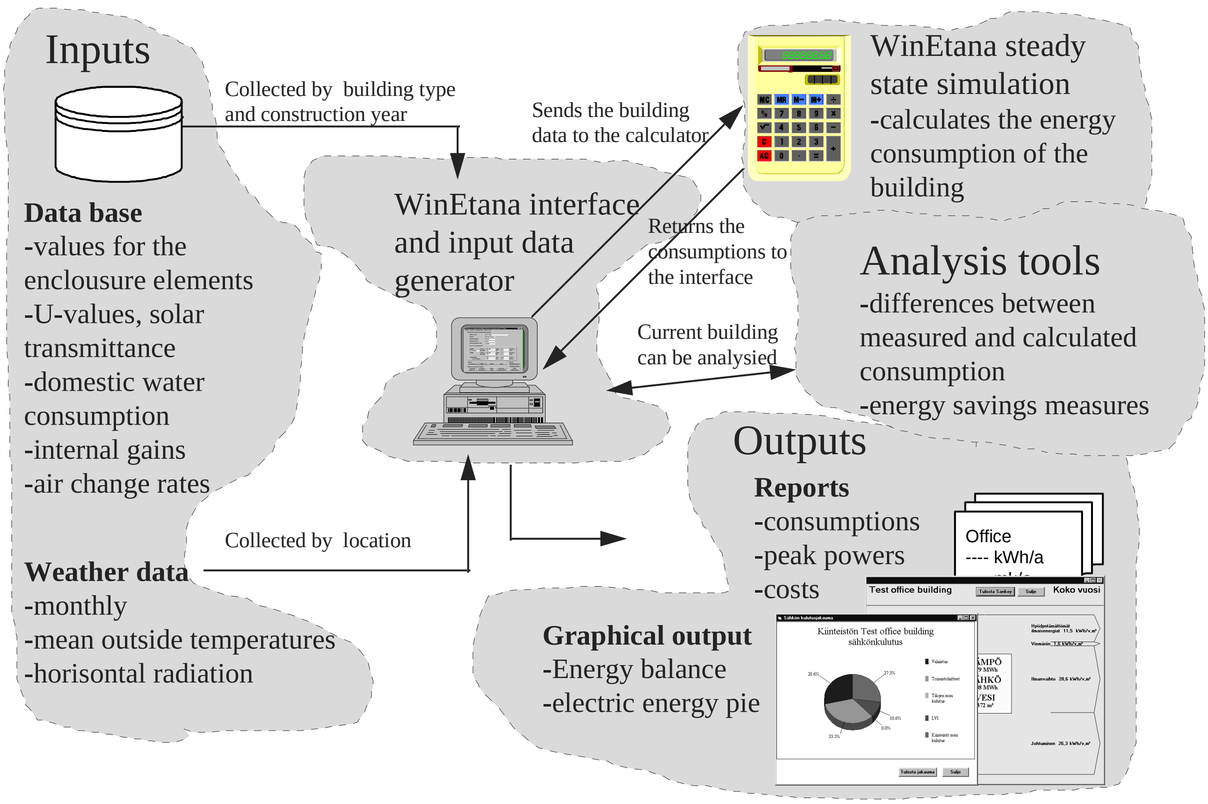

Figure 3. Different parts of the WinEtana calculation environment.

CALCULATION METHOD

The calculation method is based on the simple single-zone steady-state thermal analysis. The calculation is based on the Finnish Building Regulation D5 (National Building. 1985) and the European standard proposal (used for the calculation of the utilization factor) (prEN 832 1994).

The energy consumption in the building is calculated as followed:

1. Calculate the heat losses: heat losses through the envelope, heat losses of the ventilation (leaks and air handling units).

2. Calculate the heat loads of the building (internal and external) and their utilize factor according to the proportion of the heat loads and heat losses.

3. The net energy consumption is the sum of the heat losses and the energy need for the domestic hot water decreased by the utilized heat loads.

The calculation is made monthly. The total energy consumption is the sum of the monthly consumptions:

$$Q_{heat} = \sum_{i=1}^{12}\left(Q_{loss,i} - \eta Q_{gain,i} + Q_{domwat,i}\right) \quad (1)$$

The heat losses of the building during the calculation period are:

$$Q_{loss} = G_0\left(T_{in} - T_{out}\right)\Delta t + G_{ground}\left(T_{in} - T_{ground}\right)\Delta t \quad (2)$$

where G_0 is the total conductance (includes the walls, windows, roofs and the air change:)

$$G_0 = G_{walls} + G_{windows} + G_{uppfloor} + G_{vent} + G_{leaks} \quad (3)$$

where

$$G_{walls} = U_{walls}A_{walls} \quad (4)$$

$$G_{windows} = U_{windows}A_{windows} \quad (5)$$

$$G_{uppfloor} = U_{uppfloor}A_{uppfloor} \quad (6)$$

$$G_{leaks} = \frac{\rho_{air}c_{p,air}n_{leaks}V_{build}}{3600} \quad (7)$$

The ground floor conductance is:

$$G_{ground} = U_{ground}A_{ground,eff} \quad (8)$$

The conductance for the air change is:

$$G_{vent} = \dot{m}_{air}c_{p,air}\left(1-\varepsilon\right)\frac{n_{hourday}n_{dayweek}}{168} \quad (9)$$

The total gains are calculated:

$$Q_{gain} = Q_{sol} + Q_{occ} + Q_{app} + Q_{domwat,util} \quad (10)$$

where solar gains

$$Q_{sun} = \tau C_{shade}C_{trans}q_{hor}A_{window} \quad (11)$$

Assuming perfect control of the heating system, the parameters having the greatest influence on the utilization factor are the gain/loss -ratio:

$$\gamma = \frac{Q_{gain}}{Q_{loss}} \quad (12)$$

and the time constant of internal structures:

$$\tau = \frac{C}{H} \quad (13)$$

where C is an effective thermal capacity of the zone that is the heat stored in the structure of the building if the internal temperature varies sinusoidally with a period of 24 h and an amplitude of 1 K. H is the specific heat flow to structures during 24 h.

Then the utilization factor is calculated:

$$\eta = \frac{1-\gamma^a}{1-\gamma^{a+1}} \quad \text{when } \gamma \neq 1 \quad (14)$$

$$\eta = \frac{a}{a+1} \quad \text{when } \gamma = 1 \quad (15)$$

where

$$a = a_0 + \frac{\tau}{\tau_0} \quad (16)$$

where $a_0 = 1$ and $\tau_0 = 16$ h in monthly calculation.

ACCURACY OF THE METHOD

The accuracy of the calculation method (when the calculated consumption and the actual consumption of the building are compared) depends mainly on the quality of the input data. Some of these data, for example the air change rate, aren't known exactly. The calculation normally contains assumptions about the behaviour of the occupants, electric energy use and so on.

The uncertainty of the input data proceeds through the calculation via formulas and equations, resulting a generally larger error in the results. In particular, when the gains are high compared to losses in the building, the small heat requirement is a result from the subtraction of two large numbers (losses - gains).

Therefore, it's recommended to give a great care to the input data, and perform an error analysis taking account of the uncertainties of the input data, when the yearly heat requirement is smaller than one third of the loss (prEN 832 1994).

VERIFICATION OF THE TOOL

The simulation tool uses a simple single-zone steady-state thermal analysis. The calculation is based on the Finnish Building Regulation D5 (National Building. 1994). The calculation method was tested and verified to dynamic simulations and to measured consumptions in a test building located in southern Finland. Steady state method showed good significance related to the dynamic simulations and also to the measured consumption values (Kalliomäki 1989). Here must be pointed out, that steady state methods usually give good results in Finnish climate, because most of the year (about nine months) buildings need heating and solar gains don't play very significant role.

To arising discussion, this steady state method was compared to IEA BESTEST results calculated by some dynamic programs (Haapala et al 1995). Same benchmark test module (presented in the source) of the commercial building was used than the dynamic programs did.

The BESTEST module contained two office rooms and a corridor and it was located in Denver Colorado. The calculation was made monthly. Indoor set point temperature was 20 ^{o}C at day time (7 am. - 5 pm) and 18 ^{o}C at night time. The results of the steady state WinEtana compared to the other dynamic programs are shown in table 1.

Table 1. Calculated heating energy consumptions in the IEA BESTEST module with different simulation programs (Haapala et al 1995). Last row contains difference between steady state WinEtana and average values of the dynamic programs in BESTEST.

Program	**Case 1a** orientation south-north, no shade	**Case 2a** orientation east-west, no shade
Mean for all DYNAMIC PROGRAMS (MWh)	1.27	1.40
	Relative difference (%)	
BLAST	-1	-2
ESP	-25	-17
SERI-RES	+8	+1
S3PAS	+22	+22
TASE	0	+2
TRNSYS	-4	-5
WinEtana compared to BESTEST average	+2	+2

Because the WinEtana couldn't calculate directly the effect of night set-back in heating, there were used a time weighted constant indoor temperature (18.8 ^{o}C) for calculations. Also the solar transmittance of the windows is constant (0.75) for the whole year. In this benchmark case, these are the main error sources for the calculation. There were made a sensitivity analysis for these two parameters. Assuming a possibility of a 10% error for solar transmittance and a 0.8 ^{o}C error for indoor set point temperature, the calculation results are according to the sensitivity analysis:

Case 1a orientation south-north:

1.30 ± 0.12 MWh/a (only transmittance)

1.30 ± 0.25 MWh/a (both)

and

Case 2a orientation east-west :

1.43 ± 0.10 MWh/a (only transmittance)

1.43 ± 0.22 MWh/a (both)

The error of solar transmittance and indoor setpoint temperature is in all between 15-19% to the total heating energy consumption. When the effects are separated, the effect of solar transmittance is between 7-9% and the effect of indoor setpoint temperature between 8-10%.

The commercial building test case used here is on the limit where the stedy state method begins to be uncertain. Still, the main point is that the results don't differ from the dynamic simulations more than among dynamic simulations usually.

VERIFICATION OF DEVELOPED ANALYSIS METHOD

The developed energy analysis method has verified co-operationing with The Helsinki City Public Works. At the beginning the target energy consumption has calculated with following few inputs parameters:

- building category,
- year of construction,
- climate zone,
- building volume,
- shape of building and
- number of storey and storey height.

Rest parameters are taken from data base. Data base take into accounts e.g. old building regulations, design practises and also electricity and water consumption statistics.

The calculated consumptions were compared with the measured values (figure 5) and it was noticed that there were in five cases from nine significant difference between these values. The reasons for differences were analysed by auditing .

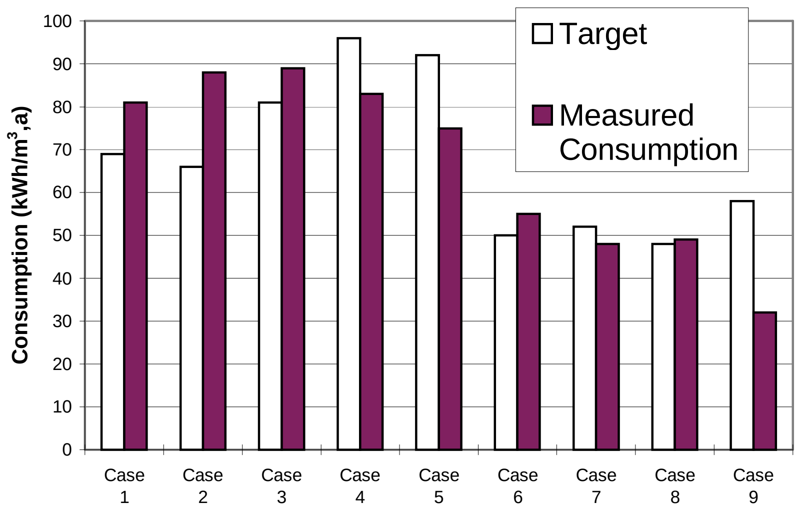

Figure 5. The calculated target and measured space heating consumptions of nine test cases.

The results of 9 audited buildings show that in 7 building ventilation is the main or significant reason for difference. The reasons for these differences were analysed more carefully and the following reason were found:

- Case 1: operation time of fans 1,5 h/day too long. Exhaust fans work unnecessary long time (24 h/d).
- Case 2: operation time of fan about 1 h/day too long. Indoor temperature about 1 deg.^{o}C higher than in the target energy consumption calculation.
- Case 3: supply air flow too high (expected not measured).
- Case 4: operation time of exhaust fans smaller than in the target energy consumption calculation.
- Case 5: the supply air flow rate too high (expected not measured).
- Case 6: the target and measured values about the same.
- Case 7: the target and measured values about the same.
- Case 8: ventilation rate lower than in calculation (expected not measured).
- Case 9: indoor air temperature lower than used in calculation but also heat recovery efficiency lower than in calculation. In this case the target and measured values were about the same: the faults were not discovered before auditing.

In eight cases out of nine the method works fine. Only in one case (case 9) the problem in ventilation was not detected, because two faults compensated each other (low indoor temperature and low efficiency of heat recovery unit).

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CONCLUSIONS

Carried out studies indicate that there is a potential to improve the energy economy and the function of ventilation of individual buildings. Energy analysis which is assisted with simulation tool is an efficient method to determinate the target values to energy consumption and to estimate energy saving potential. The developed tool which is based on simple calculation method and minimum information of building seems to work well. The strategy in which input values are defined during the process is efficient and results are reliability when the heating demand compared to heat gains is over 30 % as it is in Northern Europe.

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NOMENCLATURE

Symbols

Δt	calculation period	h
A	area	m^2
C	specific heat capacity	kJ/kg,°C
C	solar energy conversion factor	(-)
G	thermal conductance	kW/°C
$\dot{m}$	massflow	kg/s
n	air change rate	1/h
n	number of operation hours or days of ventilation	(-)
Q	energy	kWh
T	temperature	°C
U	U-value	W/m^2,°C
V	volume	m^3

Subscripts (abbreviations)

app	electric appliances
build	building
dayweek	days per week
domwat	domestic hot water
eff	effective
heat	heating
hor	horizontal plane
hourday	hours per day
i	current calculation period
in	inside
occ	occupancy
out	outside
shade	solar shading
sol	solar
trans	solar transmittance
uppfloor	upper floor
util	utilized
vent	ventilation

Greek letters

η	utilization factor	(-)
τ	time constant	h
γ	gain/loss-ratio	(-)
ε	heat recovery efficiency	(-)