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A Comparison of Energy Calculations for a Single-Family Detached Home with Two Energy Simulation Methods

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Abstract**—**For newly produced houses and energy renovations, an energy calculation needs to be conducted. This is done to verify whether the energy consumption criteria of the house -to reach the energy targets by 2020 and 2050- are in-line with the norms. The main purpose of this study is to confirm whether easy to use energy calculation software or hand calculations used by small companies or individuals give logical results compared to advanced energy simulation program used by researchers or bigger companies. There are different methods for calculating energy consumption. In this paper, two energy calculation programs are used and the relation of energy consumption with solar radiation is compared. A hand calculation is also done to validate whether the hand calculations are still reasonable. The two computer programs which have been used are TMF Energi (the easy energy calculation variant used by small companies or individuals) and IDA ICE - Indoor Climate and Energy (the advanced energy simulation program used by researchers or larger companies). The calculations are done for a standard house from the Swedish house supplier Fiskarhedenvillan. The method is based on having the same conditions and inputs in the different calculation forms so that the results can be compared and verified. The house has been faced differently to see how the orientation affects energy consumption in different methods. The results for the simulations are close to each other and the hand calculation differs from the computer programs by only 5%. Even if solar factors differ due to the orientation of the house, energy calculation results from different computer programs and even hand calculation methods are in line with each other.

Keywords**—**Energy calculation, energy consumption, energy simulation, IDA ICE, TMF Energi.

I. Introduction

EUROPE has adopted a well-determined vision for improvement of energy performance of its buildings by introducing Energy Performance of Buildings Directive (EPBD) [1]. Approximately 40% of the total energy consumption in the EU is attributed to the building sector. Due to this fact, buildings are important players in aiming towards the international energy conservation targets [2]. Almost 70% of the consumed energy households in the EU are attributed to heating [3], and building renovation is the most effective energy saving measure to reach modern energy standards [4]. These upgrading measures include upgrading doors and windows to ones with less thermal transmittance and leakage, increasing insulation properties of roofs, floor and external walls and upgrading the HVAC (Heating, Ventilation, and Air Conditioning) systems.

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An effective and proven way to calculate the energy consumption of a building before and after renovation- and thus assessing the effect of different energy conservation measures in renovation- is to use a well-proven energy simulation software such as IDA ICE. Moreover, according to Sweden’s National Board of Housing, Building, and Planning [5], for every house that is built or renovated, whether large or small, an energy calculation must be made to verify whether the new construction fulfils the requirements. In the building permit documents submitted to the municipality, a calculated value must be found.

An energy calculation can be done in different ways and methods with the goal of ending up as close to reality as possible. Calculation by hand forms the historic basis of all methods, but a hand calculation cannot be as advanced as a simulation in an advanced computer program. However, using an advanced energy simulation program requires a good level of energy knowledge and deep level of understanding energy systems and all the building parts. This level of knowledge is not available in many of mid-size and small-size building companies that plan and perform energy renovations. Therefore, these companies go towards using more simple energy software or easy, table-dependent hand calculations.

In this paper, two different energy calculation programs – one using an advanced, well-proven energy software (IDA ICE) and one using a simple, easy to use energy software (TMF Energi)- and a calculation by hand have been compared for a single-family detached house.

II. Aims and Approach

In this study, annual energy consumption of a single-family detached house will be simulated using two energy simulation software; TMF Energi and IDA ICE (Indoor Climate and Energy). TMF Energi is a medium level Swedish local energy calculation software which is based on degree-hours method. IDA ICE is a building performance simulation software for the multi-zonal and dynamic simulation of indoor climate as well as energy usage on an hourly basis. Annual energy consumption level with both computer programs will be compared and analyzed. The effect of other important design parameters such as building orientation and windows insulation technology on the annual energy consumption will be also compared and discussed. A hand calculation will be made to compare if the calculated energy consumption level using hand-calculations and simple energy software (TMF

Energi) are reasonable compared to the advanced energy simulation software (IDA ICE).

III. Hand-Made Energy Calculations

A. Energy Consumption Due to Heating

The energy use of the building is calculated according to [6] and [7]. Total energy consumption is obtained from (1) and for the specific energy use, (2) can be used:

$$E_{total} = E_{heating} + 365 \times (E_{el} + E_{hw}) + E_{ree} \quad (1)$$

where E_{total} = Annual building energy usage [kWh]; $E_{heating}$ = Heating energy [kWh]; E_{el} = Domestic electricity usage [kWh]; E_{hw} = Hot water energy [kWh], E_{ree} = Real Estate Energy [kWh].

$$E_{spec} = E_{total}/A_h \quad (2)$$

where, E_{spec} = Annual specific energy consumption [kWh/m^2]; A_h = The area with a temperature of 10°C or higher [m^2].

Calculation method for energy consumption requirements for heating is conducted using (3) and (4). Q is the specific energy loss factor [W/°C] and T is temperature [°C]. T_{limit} is the boundary temperature up to which the heating system warms up the building.

$$E_{heating} = Q_{total} \sum_{i=1}^{8760} (T_{limit} - T_{outdoor}) * \Delta t \quad (3)$$

in which,

$$Q_{total} = Q_{transmission} + Q_{ventilation} * (1 - \eta) + \boldsymbol{Q_{leakage}} \quad (4)$$

$$\sum_{i=1}^{8760} (T_{limit} - T_{outdoor}) * \Delta t = D_h \ [°C * h]$$

D_h is degree hours which can be found in [8].

To calculate Q_{total} in (4), specific transmission loss ($Q_{transmission}$), specific ventilation loss ($Q_{ventilation}$) and specific air leakage loss ($Q_{leakage}$) are required, which can be calculated from (5)-(7).

$$Q_{transmission} = \sum_{i=1}^{n} U_i * A_i + \sum_{k=1}^{m} \Psi_k * l_k + \sum_{j=1}^{p} X_j \quad (5)$$

in which U_i = The heat transfer coefficient of a building component [W/m^{2}K]; A_i = Building part's interior area [m^2]; Ψ_k = Heat transfer rate for linear thermal bridge [W/m.K]; l_k = Length of linear thermal bridge [m]; X_j = Heat transfer rate for point thermal bridge [W/K].

$$Q_{ventilation} = \rho * c_p * q_v \quad (6)$$

in which ρ = Air density, 1.2 *kg/m*^{3}; cp = Specific heat capacity of the air, 1000 J/kg·K; q_v = mechanical ventilation flow rate [m^3/s]

$$Q_{leakage} = \rho * c_p * q_{leakage} \quad (7)$$

in which ρ = Air density, 1.2 *kg/m*^{3}; c_p = Specific heat capacity of the air, 1000 J/kg·K; q_v = Air flow rate through leakage [m^3/s].

To calculate the energy consumption for a whole year, a method with degree hours (D_h) is used. To determine D_h, the normal year temperature for a municipality (T_{ny}) and the boundary temperature (T_{limit}) is needed. T_{limit} is the temperature to which heating takes place, as there is free energy from internal gains (occupants and electrical equipment) and solar radiation and can be calculated from (8).

$$T_{limit} = T_{indoor} - \frac{E_{free}}{Q_{total}} \quad (8)$$

where E_{free} = The amount of free energy [W], T_{indoor} = Indoor temperature [°C].

More detailed information about the hand-made calculations can be found in [6], [7].

B. Energy consumption due to domestic hot water

For calculation of energy consumption due to domestic hot water $E_{hot\ water}$, (9) is used in which $A_{tempered}$ is the tempered area which is heated by the heating system to at least 10 °C [6], [7].

$$E_{hot\ water} = 5.0 * number\ of\ apartments + 0.015 * A_{tempered} \quad (9)$$

IV. Energy Calculations in TMF Energi Computer Program

The Research Institutes of Sweden [9] was commissioned to develop a calculation aid for the energy usage in single-family detached houses. It began when Sweden adopted the EU EPBD and major demands were made on new buildings legislation. The small house manufacturers needed a calculation program so that they could more easily calculate and verify the specific energy use [10], [11].

The calculations in TMF mainly follow SS-EN ISO 52016-1:2017 and with duration charts from SMHI (Swedish Meteorological and Hydrological Institute). Since SS-EN ISO 52016-1:2017 deals mainly with the heating requirement in the building, therefore TMF Energi has been supplemented with hot water use and various technical installation solutions [12]. TMF Energi is not a separate program but is built up in Excel; a separate subroutine is used to repeatedly make calculation methods. This means that TMF Energi works well in Excel even though there are many calculations at the same time [10].

V. Energy Simulations in IDA ICE Computer Program

IDA indoor climate and energy (IDA ICE) is an energy simulation tool developed by the Swedish company EQUA Simulation AB, which was founded in 1995. IDA ICE uses three parts as a basis for the simulation, building climate shell, HVAC systems and control systems for calculating energy use and indoor climate. In the program, several zones can be added to obtain detailed results on energy usage and temperatures in different places in the building. A zone can be a room, an entire apartment or an entire house [13].

There are 3D interfaces and detailed tables which make it easy to see how the program interprets input, which facilitates the refinement of the model. All work is in one and the same program, which facilitates when all information is collected on the same file.

It is possible to import BIM (Building Information Modeling) files in order to be able to import building geometry files from BIM tools e.g. ArchiCAD, Revit, AutoCAD Architecture and MagiCAD.

In IDA, equation-based modeling is possible with the Neutral Model Format (NMF). This enables new modeling functions, which can be designed in IDA's developer or more advanced for the experienced user. The program has transparency because all underlying equations are possible to read, and thus all variables can be examined, such as temperatures, heat flows, air velocity fields, Humidity ratio, CO_2 levels and so on.

Another unique characteristic of IDA ICE is using a variable time step solver, instead of using the hand-coded subroutines that almost all other whole-building simulators utilize. Therefore, it automatically adapts to the nature of the problem. By the choice of tolerance parameters, the program can eliminate numerical errors and assess the validity of governing equations.

All above have made IDA ICE a complicated but reliable simulation tool for energy and thermal comfort, and that is why it has been selected as the reference tool in this study.

VI. Test Object (Single-Family House)

The test object is one of Fiskarhedenvillan's standard houses called Talgoxen [14]. Talgoxen is a single floor house which consists of a kitchen, a living room, three bedrooms with walk-in closet, two toilets with shower, a laundry room and a working/guest room. All these rooms result in a bottom plate of 144.9 m^2. Plan and section and façade drawings of the house are shown in Fig. 1.

The building's surrounding area is 445.2 m^2 and its volume is 397.2 m^3. The average thermal transmittance is assumed to be 0.20 W/m^{2}K with outer walls thickness of 370 mm (with 260 mm insulation thickness) and a U-value of 0.16 W/m^{2}K. The U values for the ceiling and the floor are 0.09 W/m^{2}K and 0.12 W/m^{2}K, respectively.

Outer doors have a U-value of 1.0 W/m^{2}K, and glass doors (ADK on the drawings) have a U-value of 0.9 W/m^{2}K.

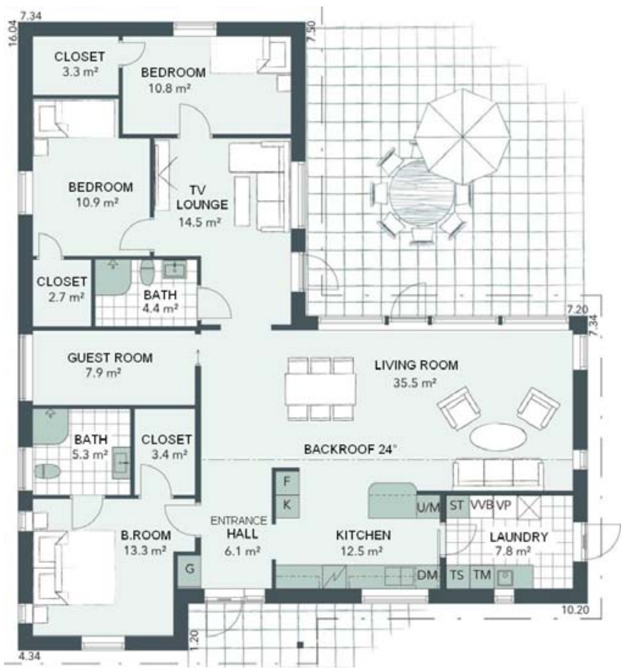
The geographical point of the house is Västerås city in Sweden.

The building's exhaust air is the minimum requirement in in Swedish regulations which is 0.35 liters/(s.m^2) and there is no mechanical supply air but there are fresh outdoor air ducts at some of the windows. The house tightness is 0.8 liter/(s.m^2) at a pressure difference of 50 pascals according to EN ISO 9972: 2015 [15].

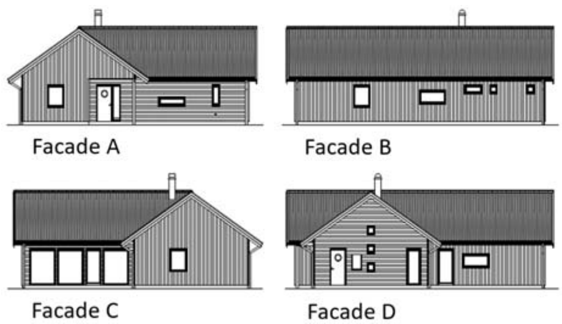
VII. Results

A. Hand-Made Energy Calculations

The hand calculations have resulted in three different values (Figs. 2 and 3), whereas the difference between the calculations is the orientation of the house. The noted direction means that the entrance door is facing that direction. For the façade facing north, the annual specific energy consumption becomes 37.26 kWh/m^2 tempered area and the amount of purchased energy without household electricity equals 5,398 kWh annually. The specific energy usage for the west-oriented facade results in 46.09 kWh/m^2 and the purchased energy becomes 6,679 kWh. South and east faced façade orientations are close together during the calculation and their specific energy consumption and purchased energy becomes 53.4 kWh/m^2 and 7,737 kWh, respectively.



(a)



(b)

Fig. 1 (a) Plan and section drawing and (b) facade drawing of the test object

B. Calculations in TMF Energi Computer Program

The only difference between the three different simulations is the passive solar radiation parameter (Figs. 2 and 3).

C. Energy Consumption Simulations in IDA ICE Computer Program

The four different bars represent a separate outline (Figs. 2 and 3). For example, "North" means that the entrance door is facing north. Then the house has been rotated 90° clockwise at a time for the remainder.

D. Results comparison

In Figs. 2 and 3, the results of the three different calculation methods are presented and can be compared. The green bars are results from TMF Energi, the red ones are results from IDA ICE and the blue ones show the hand calculation results.

Simulations in TMF Energi have notations high, normal and low. This means that the amount of passive solar radiation differs from one another, which means that there is a lot of solar radiation, for example with large windows in the south.

From IDA ICE, the simulations give four different results, as shown in red bars in Figs. 2 and 3. Unlike TMF Energi, no parameter changed for the passive solar radiation without the house being rotated. North, West, South and East indicate the direction the entrance door is facing.

Three sets of results have come from hand calculations which are shown in blue bars in Figs. 2 and 3. North, West, and South/East indicate the direction the entrance door is facing.

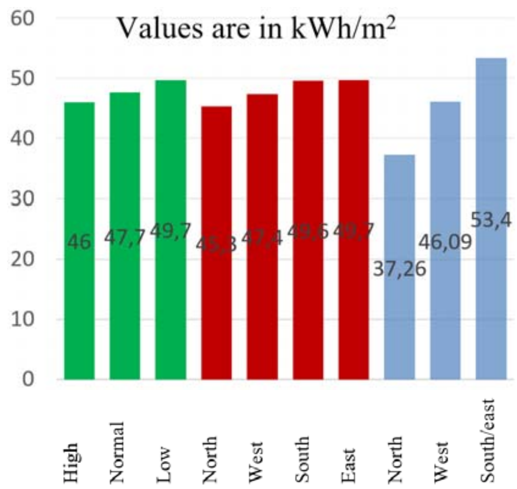


Fig. 2 Specific energy consumption results for different scenarios from TMF Energi (Green bars), IDA ICE (red bars) and hand calculations (blue bars)

VIII. Discussion

The result for the hand calculation differs from the computer calculation programs while the different simulation programs are close together. The orientation of the various programs and passive solar radiation can easily be matched together in Figs. 2 and 3. When the entrance is facing north, the large window section is towards the south, which is the most sun-exposed side of the house and a clear similarity exists between the north bar in IDA ICE and high bar in TMF Energi. The same similarity can be drawn between the other bars; west is similar to normal and the south and east are similar to low.

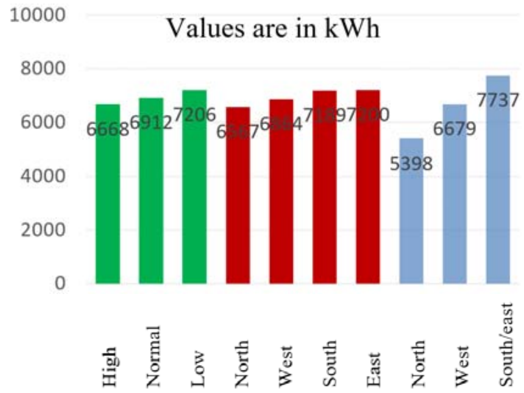


Fig. 3 Purchased energy results for different scenarios from TMF Energi (Green bars), IDA ICE (red bars) and hand calculations (blue bars)

In Figs. 2 and 3, it is easy to see how much difference could be due to the orientation of the house and the solar radiation, between the smallest and largest values from the computer programs and the hand calculations.

The difference of results obtained from the different simulation programs became very marginal and the energy consumption results are analogous to each other.

The energy consumption varies greatly depending on the location of the house and the windows. It can be concluded that if the simulations had been carried out on a house with even larger glass sections, the difference between TMF Energi and IDA ICE results would have been even larger. The former is due to the fact that in TMF Energi there are only three positions to choose for the solar radiation while in IDA ICE – as an advanced energy program- it depends on the location of windows in the 3D model.

Calculating the average of computer programs' different results gives average specific energy consumption values of 47.8 kWh/m^2 for TMF Energi and 48 kWh/m^2 for IDA ICE. The mean value of the hand calculation for specific energy consumption in different cases becomes 45.6 kWh/m^2 which indicates a difference of about 5% from the computer programs. This 5% can be attributed to rounding off during the calculation once, or the rough estimates of the weather data which were generated degree hours D_h value, or even the effect of boundary temperature T_{limit} that had to be rounded to suit degree hour values.

The results of this study show that, the simpler energy calculation programs –which do not require expert energy knowledge- have also the possibility to give acceptable energy results at least for every day single-house construction and renovation works.

It is good to mention that for the case of energy calculations regarding multi-family houses or even single houses which adopt innovative passive design or complicated building services engineering, the difference might have been larger and thus, an advanced energy program shall be utilized by an energy expert. Last but not least, there are of course many benefits in more advanced energy simulation software (such as IDA ICE) that are not available in simple software (such as TMF Energi). As an example, 3D modeling gives a detailed picture of the building design and specifications, all building parts and even control strategy can be dynamically simulated for every hour of the year, and all the energy and indoor climate data can be simulated for several zones.

IX. Conclusions

Important conclusions from the study are:

- Results from the simple computer program TMF Energi and the advanced software IDA ICE did not differ much from each other. Thus, for every day small single-house construction and renovation works, the simpler computer energy programs (such as TMF Energi) work best for smaller companies since they are cheap and easy to operate and give trustable results. More advanced energy software (such as IDA ICE) requires an energy expert and takes much longer time to simulate building's energy performance. However, the advanced energy software should be considered to be used if the house has a more complex architecture, has innovative passive design or complicated building services engineering, is a bigger building or a multi-family house, or thermal comfort and fluid properties in different zones are to be simulated.
- Location and orientation of houses and windows affect the energy demand to a high degree. According to the computer simulation programs, it can differ approximately 8%, which is considerable. Even if solar factors change in the different computer programs, results can be matched to form a pattern. Moreover, the same patterns can be seen in the hand calculation method, but with a greater deviation.

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References

[1] European Parliament, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the Energy Performance of Buildings (recast), Official Journal of the European Union L153 (2010) 13–35.
[2] The European Parliament and the Council of the European Union. Directive 2010/31/EU on the energy performance of buildings. Official Journal of the European Union, L 153 (2010) 13–35.
[3] European Environment Agency. Energy and Environment Report, 2008. ISBN: 978-92-9167-980-5.
[4] European Commission Environmental Improvement Potentials of Residential Buildings (IMPRO-Building). Office for Official Publications of the European Communities, 2008. ISBN: 978-92-79-09767-6.
[5] Boverket, Bygg och renovera energieffektivt (energy efficient building and renovation), 2017, Accessed 15 April 2019 at https://www.boverket.se/sv/byggande/bygg-och-renovera-energieffektivt/
[6] Warfvinge, C., Dahlblom, M, 2010. Projektering av VVS-installationer. Lund: Johanneshov, ISBN:9789144055619.
[7] Boverket, Konsoliderad version av Boverkets byggregler – föreskrifter och allmänna råd, 2018, Accessed 20 April 2019 at https://www.boverket.se/sv/lag--ratt/forfattningssamling/gallande/bbr---bfs-20116/
[8] Jensen, L. (Processed by Warfvinge, C.), 2001, Värmebehovsberäkning (Heat requirement calculation), Accessed 25 April 2019 at http://www.hvac.lth.se/fileadmin/hvac/files/varmebeh.pdf
[9] RISE, About RISE, 2019. Accessed 20 April 2019 at https://www.ri.se/en/about-rise
[10] TMF, About TMF energi, 2017. Accessed 28 April 2018 at http://www.tmf.se/siteassets/bransch/teknik--forskning/tmf-energi/tmf-energi-bakgrund.pdf
[11] European Commission, Directive 2010/31/EU of the European Parliament and of the Council of 19 May 2010 on the energy performance of buildings, 2010. Accessed 10 February 2019 at https://eur-lex.europa.eu/legal-content/EN/ALL/;ELX_SESSIONID=FZMjThLLzfxmmMCQGp2Y1s2d3TjwtD8QS3pqdkhXZbwqGwlgY9KN!2064651424?uri=CELEX:32010L0031
[12] Swedish Standard Institute, Energy performance of buildings - Energy needs for heating and cooling, internal temperatures and sensible and latent heat loads - Part 1: Calculation procedures (ISO 52016-1:2017), 2017. Accessed 20 April 2019 at https://www.sis.se/en/produkter/construction-materials-and-building/protection-of-and-in-buildings/thermal-insulation-of-buildings/ss-en-iso-52016-12017/
[13] EQUA, IDA Indoor Climate and Energy, 2018. Accessed 25 April 2019 at https://www.equa.se/se/ida-ice
[14] Fiskarhedenvillan, official website, 2019. Accessed 10 August 2019 at https://fiskarhedenvillan.se/
[15] International Organization for Standardization, Thermal performance of buildings -- Determination of air permeability of buildings -- Fan pressurization method, 2015. Accessed 20 April 2018 at https://www.iso.org/standard/55718.html