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GLAZED SPACE THERMAL SIMULATION WITH IDA-ICE 4.61 SOFTWARE - SUITABILITY ANALYSIS WITH CASE STUDY

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ABSTRACT

Many previous articles point out the need of using accurate energy simulation program for studying the indoor climate and energy use of the highly-glazed spaces. This article examines the suitability of IDA Indoor Climate and Energy (IDA-ICE) software for the glazed space energy simulation in theory and practice. The analysis of how the program meets highly-glazed space simulation needs has been done and comparison to the actual field measurement case conducted by using two different window and zone models featured by the simulation tool to examine the software function in practice. The measured data is from the two flats and attached balconies situated in Tampere (61°29′53″N, 023°45′39″E), Finland.

The final outcome was that the IDA-ICE 4.61 is well suited for the glazed space studies and the most accurate results are achieved by using a detailed window and zone models. Critical input parameters were the absorption coefficient of the surfaces, the balcony’s unintended ventilation, external shading and building supply air flow rate from the outside to apartment through the balcony. The results show that in design situation where attached balcony’s one side is glazed and two sides opaque, the uncertainty of the input parameters can easily cause greater deviation between measured and simulated indoor temperatures than the deviation caused by the use of different zone and window models.

Keywords: glazed balcony; glazed space; field monitoring; temperature measurement; IDA-ICE; building energy simulation
1 INTRODUCTION

A number of studies have shown that highly-glazed spaces have many good features. Temperatures within enclosed spaces are higher than outdoors [1, 2, 3, 4, 5, 6, 7, 8, 9] and their relative humidity is lower [4, 5, 10] throughout the year. As a result, there are less problems with façade degradation [6] and thermal bridges. Sunspaces also provide a buffer space against wind pressure and make it possible to take pre-heated supply air from the glazed space to reduce building energy consumption [4, 5, 7, 10, 11].

Assessing the energy saving effects of glazed space, the air temperature measurements are considered to be a useful method for the starting point of the evaluations. They reveal the dominant pathways of heat gain and loss and give an indication of thermal buffer effects and thermal comfort [12, 13]. Combining air temperature measurement with internal and external surface temperature measurements by using thermocouples, it is also possible to evaluate materials’ ability to store and release heat energy [14] and thus figure out the whole idea of thermal behaviour of glazed spaces. Obtaining better understanding of different factors affecting the temperature behaviour of glazed spaces, detailed energy simulations is often needed. For that reason, simulation programs have been widely used in sunspace studies for several decades [2, 3, 7, 8, 9, 10, 15, 16, 17, 18, 19, 20, 21]. The purpose of the simulations has mainly been to validate the used simulation programs [17, 18, 19], obtain better understanding of one or more influential factors [7, 10, 21, 23, 24] and conduct a sensitivity analysis [25] as well as develop and verify a simulation model [16]. In these studies, simulation programs have proven to be very useful tools.

Many commonly used building-energy simulation tools are not well suited for indoor climate evaluations of highly-glazed spaces due to their simplified calculation method for solar radiation transmission through windows, distribution inside the sunspace and reflection inside or outside the glazed space. That is why many previous studies have expressed the need of a detailed calculation model for studying the indoor climate of highly-glazed spaces [17, 18, 20, 26, 27, 28, 29]. Previous studies have also shown that the most accurate assessment of indoor climate may be provided by a dynamic building simulation software, which utilises state-of-the-art calculation methods for short- and long-wave radiation and radiations distribution inside glazed space as well as
between the glazed space and the adjacent room taking into account the portion of the short-wave radiation escaping from the sunspace [18, 28]. The needs of detailed energy flow through the windows [22], stratified air temperatures in the rooms [20] and detailed analysis of the airflow within the rooms [20] are also highlighted. For that reason, the calculation software’s calculation methods should be carefully found out before making a final decision on the used program.

This article evaluates the suitability of the IDA Indoor Climate and Energy (IDA-ICE) software for the glazed space energy simulation. The paper describes the critical parameters of the highly-glazed space simulations (Introduction) and analysis of how the program meets these needs (Background). In addition, the analysis has involved an actual field measurement case, in which the effect of the software’s different model detailing level to the calculation results has been examined. Object of the study has been a) to analyze the suitability of the program to highly-glazed space simulation in theory and practice, and b) bring out the key measurement and calibration parameters. The results can be used to develop the field measurement practices and simulation methods.

2 SIMULATION TOOL - BACKGROUD

IDA Indoor Climate and Energy (IDA-ICE) is one of the twenty major building energy simulation programs [30], and according to the literature review [31], one of the four main building energy simulation tools, discussed in most articles dealing with the validation of building energy simulation models. The software as many other whole building simulation tools is based on the building geometrical description, which provides the basis for a more detailed calculation of the distribution of solar radiation in and between rooms. The software calculates energy balances dynamically taking into account climatic variations and a dynamically varying time-step. The software solves heat balance equations according to the user defined building geometry, construction, HVAC conditions and internal heat loads. Software allows use of measured climate and weather file containing the information about air temperature, relative humidity, wind direction and speed, direct normal radiation and diffuse (sky) radiation on a horizontal surface and calculates for example solar radiation based on the building location and sun position in the sky. Accuracy of the IDA-ICE simulation tool has been examined in many validation studies in
recent years [32, 33, 34, 35, 36, 37, 38, 39, 40, 41]. Accordingly, selection of the IDA-ICE as the simulation tool for highly-glazed space simulation is well grounded. [30, 33, 34, 42]

IDA Indoor Climate and Energy software provides two different zone models. The detailed zone model with full Stefan-Boltzmann long-wave radiation has been developed for detailed calculations like indoor climate studies and the simplified zone model for energy simulation to speed up execution time in the normal design cases, where slight inaccuracy is acceptable. The difference between the models is mainly that the latter model makes a simplified calculation of the radiation exchange between all the surfaces of the room enclosure. In the energy model, the internal walls without thermal connection to surrounding zones are assumed adiabatic, whereas external walls and partitions towards other simulated zones are handled separately, because the conditions on the opposite side are different from those in the zone. The geometry of the zone is not known in detail; surface areas are known and are used for distribution of radiation. The model handles the diffuse radiation that comes into the zone from windows and from reflection of direct light (and is not reflected back out) by dividing it to the surfaces according to area rations multiplied by their absorptance. In the climate (detailed) zone model, the view factors between the surfaces are calculated and the emitted and reflected irradiation is distributed accordingly by solving a system of radiation balance equations for all the surfaces. The distribution and absorption of diffuse light at the different surfaces is treated in a similar way. As a result, properties such as the displacement ventilation and room temperatures vertical stratification in the zone as well as operative temperatures, comfort indices and daylight levels at arbitrary room locations can be calculated with this model. Climate zone model is only available for box-shaped zones (rectangular geometries) while energy model can handle different types of zone geometries. [34, 43]

In IDA-ICE direct and diffuse solar radiation is computed detailed including the exact time dependent sun position in the sky and the distribution of diffuse radiation, by default using the Perez [44] model. As a calculation of the long wave radiation between the sky and building façade, the ground temperature is assumed to be the same as the air temperature and the sky temperature five degrees below the air temperature [34]. This assumption of the sky temperature has proved to be a rather good average value over the long term [45].
The windows can be modelled using either a simple or an ISO-15099 [32] based detailed window model (Detwind) in IDA-ICE. The difference between the detailed and the simple window model is that in the former the glazing is modelled with the optical and thermal properties of all its panes and gasses in the gaps between the panes. The angle dependent optical properties of the glazing are then calculated with consideration of multiple reflections and the solar absorption in each pane. From this both the solar light and the heat transmission are calculated. Even the heat capacity of the panes is taken into account. In the simple model the optical and thermal properties for the whole glazing (at normal incidence) are given as input data. The angle dependence of the whole glazing is then calculated by using a fixed curve for the angle dependence. Integrated window shading (internal or external shades in the plane of the window) is calculated by multiplying shading effect to the basic window parameters. After transmitted inside the zone, diffuse light is spread diffusely and the direct light beam according to exact target location. After the first reflection on a zone surface, the direct beam is spread diffusely in the room. In all reflection calculations, the whole surface that is hit is regarded to reflect with equal intensity, not just the lit portion of the surface at issue. [34, 43]

IDA-ICE includes multizone airflow model and can handle four different types of airflows. Typically, the air flow goes through the supply and exhaust air terminals and through envelope air leakage path, but also openings and other additional flow paths are possible to create. In the simplest case, where the two first paths of airflows are created, the size of the third flow, through the leak, is important only to fulfill mass balance equation of air flows. [34, 43]. Air flows in leaks are based on pressure loss equation, thus the whole air flow network calculations are always involved in ICE models.

3 RESEARCH MATERIALS AND METHODS

The research material consists of acquired weather files, monitoring data from two balconies and the adjoining flats and IDA-ICE 4.61 software validation simulation results.

3.1 Climate and weather
3.2 Field monitoring

The main components of the field measurement system were a portable computer, a data logger, measurement sensors, sensor transmitters, and power sources. The measurement was controlled by the Agilent Benchlink Data Logger software and an Agilent 34970A Data Logger. The surface temperature sensors were of the LM 355 type and the air temperature sensors of the HTM100 type. Small battery-powered Comark Diligence EV (N2003 and N2013) data loggers were also used. Field measurement systems were used to measure outdoor temperature, flat temperature and balcony air temperature, as well as surface temperatures on both sides of the balcony glazing and balcony wall, door, and window (inner and outer) surfaces. Temperatures were recorded at 1-hour intervals for approx. 10 months (from 16th July 2009 to 24th May 2010).

Unshielded surface temperature sensors were placed in the two flats on top of each other in accordance with a connection diagram (Fig. 1). Balcony door sensors were installed in the middle of the glass pane and on the inner and outer side of the solid section. A total of four sensors were installed on the top and bottom part of the lower flat window. In the case of the upper flat window, sensors were also placed in the middle of the pane, outside and inside. The back wall sensors were placed case-specifically. Their placement was made difficult by the hot-water radiators located under the window, which affected the wall surface temperatures. A total of eight sensors were attached to the balcony glazing. The indoor air relative humidity and temperature (RH/T) sensor was in the living-room, near the balcony back wall, at a height of approx. 2.5 m. The distance of the sensor from
the external wall inner surface was approx. 0.5 m. The balcony RH/T sensor was close to the ceiling at a distance of approx. 0.5 m from the balcony back wall. The sensor measuring outdoor air temperature and relative humidity was on the balcony frame wall. The outdoor air RH/T sensor was protected against solar radiation and precipitation by a special factory-made outdoor sensor guard.

![Figure 1. Connection diagram of flat excluding balcony glazing.](image)

To collect simulation input data, air change rate was measured by a wing wheel anemometer, air-tightness by pressure test equipment, and thermal insulation by condition investigation equipment. In the same connection, the occupants were interviewed about their living habits and electricity consumption and the number of electric appliances they had – specific power consumption and daily operating time were also determined in cooperation with the occupants. The electricity consumption of 1,500 kWh/year of the flat proved to be clearly below the average consumption of a similar flat in Finland. Investigation focused on the flat with a glazed balcony. The other flat was assumed to be in similar use to make the indoor climate conditions and use of the dwelling unit similar in both cases. This way, the balcony glazing installed in the lower flat remained the only difference between the two.

3.3 IDA-ICE 4.61 modeling
During the research, computational analyses were carried out using the IDA Indoor Climate and Energy (IDA-ICE) 4.61 software. Building model was created by ArchiCAD software and transferred to the simulation software in the IFC format. Building external forest was estimated using architect’s city plan, on site observation and old photos and modelled as non-transparent bars. Under the simulation were two 64 m² flats on top of each other in the middle part of the building. Lower of flats has a glazed balcony, but also unglazed balcony was modelled as a zone. Apartment’s window supply air valves, balcony glazing’s air gaps and open part of the unglazed balcony were modelled as a differently sized pressure driven air flow path. Depending on the pressure difference between inner and outer side, air flowed inside or outside through these openings trying to neutralize pressure difference. Mostly air was flown from the outside of the building to the inside as a reason for building’s negative pressure generated by mechanical exhaust ventilation system.

Data on the building were acquired from the ArchiCAD model, one-time measurements of flat conditions, and inhabitant interviews. The location of electrical equipment and specific power were determined by site visits. Examinations were carried out in a flat with glazed balcony. Use of other flat was assumed to be similar, in order to standardize the indoor atmosphere conditions and use of premises as similar in both flats. The simulations

Figure 2. Illustration of the simulated apartment. Difference between flats on top of each other was only the balcony glazing installed in the lower flat.
used real temperature and humidity data measured on-site from 17th July to 31th December 2009. The temperature and relative humidity data missed due to the measurement interruption from 22th to 30th October 2009 and from 8th November to 2th December 2009, as well as wind speed/direction data from 17th July to 31th December 2009, were supplemented by weather observations at the Tampere/Pirkkala airport weather station. Radiation data from the simulation period 17th July to 31th December 2009 was from the Jokioinen Meteorological Observatory. For source information regarding the flat and use thereof, see Table 1 and Figure 2.

**Table 1. Apartments and balconies parameters**

| Location (climate condition) | Tampere (61° 29′ 53″ N, 23° 45′ 39″ E), Finland |
| Orientation | South-West |
| Wind profile | Suburban |
| Balcony façade distance from the building in front | Mixed forest in front of the balcony facade |
| Apartment size (A\textsubscript{APARTMENT}) | Two-room flat, A\textsubscript{APARTMENT}=64 m\textsuperscript{2} and V\textsubscript{APARTMENT}=166 m\textsuperscript{3} |
| Balcony size (A\textsubscript{BALCONY}) | A\textsubscript{BALCONY}=6 m\textsuperscript{2} and V\textsubscript{BALCONY}=16 m\textsuperscript{3} |
| Apartment inside air temperature | 23.3 °C |
| Standard of equipment, number of residents and apartment usage habits | According to the real situation inside the apartment (two residents, electricity consumption 1.500kWh/year) |
| Apartment type | Apartment runs from front to back of a building |
| Balcony type | Extended concrete balconies supported on frame walls |
| Building air change rate | Mostly 0.35 ACH, between 06:30-09, 11-13 and 16-18 0.7 ACH |
| Supply air inlet vents position | Two window vents |
| Glazed space unintended ventilation | 1.1-2.2 ACH (monthly average) |
| Building air leakage coefficient (at 50 Pa pressure difference) | 0.88 ACH (at 50Pa pressure difference) |
| Heating capacity design of hot water radiators | According to corrent design in 1979 |
| The heating system control curve position | According to corrent settings in the building |
| The heating system summer shut-off | No summer shut-off |
| Surfaces absorptivity (Balcony and external wall) | Mostly 0.22 (Balcony slab top side and external wall outer side 0.3, balustrade outer side 0.4) |
| Surface emissivity (Balcony and external wall) | 0.9 |
| Specific heat capacity of balcony structures | 900 J/(kg*K) |
| Lambda value of balcony structures | 1.35 W/(m*K) |
| Density of balcony structures | 2300 kg/m\textsuperscript{3} |
| Window or balcony glazing blinds placement position | No blind |
| Wall properties (wall between apartment and balcony) | A\textsubscript{WALL}=5.2 m\textsuperscript{2} and U\textsubscript{WALL}=0.3 W/m\textsuperscript{2}K |
| Window properties (wall between apartment and balcony) | A\textsubscript{WINDOW}=3.3 m\textsuperscript{2}, U\textsubscript{WINDOW}=1.4 W/m\textsuperscript{2}K, g\textsubscript{WINDOW}=0.55 |
| Balcony door properties | A\textsubscript{DOOR}=1.9 m\textsuperscript{2}, U\textsubscript{DOOR}=1.2 W/m\textsuperscript{2}K, g\textsubscript{DOOR}=0.55 |
| Balcony glazing properties | A\textsubscript{GLAZING}=6.3 m\textsuperscript{2}, U\textsubscript{GLAZING}=5.8 W/m\textsuperscript{2}K, g\textsubscript{GLAZING}=0.82 |
| Glazing-to-floor area ratio (A\textsubscript{GLAZING} / A\textsubscript{BALCONY}) | 1.05 |
| Window and door-to-floor area ratio ((A\textsubscript{WINDOW}+A\textsubscript{DOOR}) / A\textsubscript{BALCONY}) | 0.87 |
| Glazing-to-balcony glazing eligible area ratio (A\textsubscript{GLAZING} / (A\textsubscript{BALCONY WALL}+A\textsubscript{BALCONY SIDE WALL}+A\textsubscript{BALCONY FRONT WALL})) | 0.26 |

Simulation studies were performed by comparing actual air and surface temperature values to simulated ones by using four different model detailing levels (Tab. 2). The most detailed one was the simulation model with a
detailed window (Detwind) and a zone (Climate) model, while the most simplified one incorporated a simple window structure and a zone (Energy) model.

Table 2. Four detailing levels of the model used in simulation studies and their modelling times.

<table>
<thead>
<tr>
<th>Simulation cases</th>
<th>Zone and window model</th>
<th>Modelling time</th>
</tr>
</thead>
<tbody>
<tr>
<td>Most detailed</td>
<td>Climate model with detailed window</td>
<td>35 min 23 s</td>
</tr>
<tr>
<td>Detailed</td>
<td>Energy model with detailed window</td>
<td>29 min 29 s</td>
</tr>
<tr>
<td>Simplified</td>
<td>Climate model with simplified window</td>
<td>34 min 38 s</td>
</tr>
<tr>
<td>Most simplified</td>
<td>Energy model with simplified window</td>
<td>29 min 11 s</td>
</tr>
</tbody>
</table>

4. CONTEXT

4.1 Climate

The city of Tampere (61°29′53″N, 23°45′39″E) lies borderline between humid continental (Köppen-Geiger Dfb) and subarctic climate (Köppen-Geiger Dfc) [49]. City’s winter is cold and summer mild. The average temperature from November to March is below 0 °C (32 °F) and whole year below 17 °C (49 °F) (Fig. 4 a). The annual average temperature is 4.4 °C (36.4 °F). Heating degree-days (HDD17) during the normal period 1981-2010 was 4424 per year and 2009 it was 4371. [46, 50]

Autumn months of the field measurement period (July-December 2009) were unusual compared to “normal” and “typical” condition in Tampere (Fig. 3 a). August was slightly warmer, September clearly warmer (2.5 °C) and October clearly colder (-2.1 °C) than average. November was 2.2 °C milder than average and December -2.1°C colder. The year 2009 as a whole was slightly (0.1 °C) warmer than “normal” year. There was only slight difference between Tampere “normal” and “typical” year monthly average temperatures as shown in figure 3 a. [51]
Figure 3a and b. Climatic Context. 2009 monthly average temperatures and incident solar radiation levels compared to 1981-2010 “normal” and ASHRAE IWEC “typical” values. Autumn 2009 was exceptional in both mean temperature and incident solar radiation point of view. Figure shows that ASHRAE IWEC weather data overestimate clearly incident solar radiation levels in Tampere (Compered to Jokioinen “normal” and 2009 solar radiation data).

In 2009, the sunshine duration was close to long-term 1500-2000 hours average level and the total solar radiation levels a little higher than normal in August, September and October [51]. A comparison between Tampere ASHRAE IWEC and Finnish Meteorological Institute’s nearest solar radiation observatory’s 2009 and "normal" solar radiation levels shows that the ASHRAE IWEC weather files clearly overestimates the actual solar radiation level in Tampere, Finland (Fig 3b). It is therefore recommended to use Finnish Meteorological Institute’s solar radiation data in the energy simulations.

4.2 Field site

The studied building is situated in a normal Finnish urban area in Tampere (61°29’53”N, 023°45’39”E), Finland. The building is a 1+6 storey pre-cast concrete block of flats completed in 1979 with extended concrete balconies supported on frame walls (Fig 4). The building exterior wall colour is dark red, balcony structures colour mainly white and balcony back wall and floor colours light grey. Apartment interior surfaces are all light coloured.
The building is connected to the district heating network and ventilated by a mechanical exhaust ventilation system. The heating water is delivered inside the building through hot water pipes and heat gave out with the help of free-standing radiators. The facades of the building were renovated in 2004, in which connection the windows and doors were replaced and glazing was installed in about 50% of the balconies. The condition of the HVAC systems was checked at the same time and the ventilation and radiator systems were balanced. The exhaust ventilation unit was not replaced, but was equipped with modern timer control.

5 RESULTS AND DISCUSSION

5.1 Field measurement

Balcony temperatures
Temperature measurements show that temperatures inside the balconies were higher than outdoor temperatures throughout the year. On average, the unglazed balcony temperature was 0.8 °C, and the glazed balcony temperature 3.7 °C, higher than outdoor temperature. During the heating season, the temperature differences were 0.8 °C and 4.1 °C, respectively. Solar radiation has also a significant effect on the temperature conditions of glazed balconies (Fig. 5). Solar radiation in spring, for example, warmed up balconies very rapidly causing momentarily increase of the temperatures inside a glazed balcony. This phenomenon had only a slight
impact on the adjacent apartment indoor air temperatures as seen in the figure 5. The highest glazed balcony and outdoor air temperature difference was 14.0 °C measured on 12th December 2009 at 9 p.m.

![Figure 5. Balcony, outdoor air and flat temperatures from 13th to 15th March 2010. Solar radiation had a strong effect on balcony temperatures especially in spring. Solar radiation warmed up glazed space very rapidly causing great temperature difference between space and outdoors air. This phenomenon, however, had only a slight impact on the adjacent apartment indoor air temperatures as seen in the figure.]

**Flat temperatures**

Average temperature inside the flats varied from 22.0 °C to 28.4 °C and from 21.7 °C to 26.4 °C depending on whether the balcony was unglazed or glazed, respectively. On average, the flat with the unglazed balcony was 1.2 °C warmer than the flat with the glazed balcony. The greatest temperature difference between the flats was 2.1 °C (in January, the coldest winter month), and the smallest 0.2 °C (in September). The temperature difference between the flats was directly proportional to the temperature difference between the glazed and non-glazed balcony. As outdoor temperatures decreased, the temperature difference between the glazed and unglazed balcony and between adjacent flats increased, and vice versa. Possible reason for this was the draught caused by the colder air through the window supply air valve as well as colder window, door and wall surface temperatures that affect the operation of the radiator thermostat inside the flat without balcony glazing. The radiator under the window inside the flat without balcony glazing was warmer than in the other flat resulting
higher inside temperatures i.e. the installation of the balcony glazing reduced need to eliminate the sense of draught by overheating the flat.

**Balcony window, door, and back wall surface temperatures**

Balcony window, door, and back wall external surface temperatures measured inside the glazed balcony exceeded those measured inside the unglazed balcony throughout the measurement period. On average, the window, door, and wall external surface temperatures measured inside the glazed balcony exceeded the respective temperatures measured inside the unglazed balcony by 2.5 °C, 2.0 °C, and 1.4 °C, respectively. The temperature difference between the external surfaces was clearly larger during the heating season than in summertime. The temperature difference between external window surfaces was 2.8 °C in winter and 1.7 °C in summer, between external door surfaces 2.4 °C in winter and 1.3 °C in summer, and between external wall surfaces 1.6 °C in winter and 1.0 °C in summer. The measurement results indicate that balcony glazing stabilised temperature variations and temperature differences between the top and bottom edges of external window surfaces. The phenomenon was strikingly evident during the periods in which the temperature difference between the apartment and outside air was very high, as during cold winter days in January (Fig. 6), for example.

![Graph showing external surface temperatures](image_url)

**Figure 6.** Measured external surface temperatures of the windows from 5th to 7th January 2010. Balcony glazing stabilised temperature variations and temperature differences between the top and bottom edges of external
window surfaces. The phenomenon are strikingly evident during the periods in which the temperature difference between the apartment and outside air was very high, as during cold winter days in January, for example.

Internal surface temperatures of the flat with an unglazed balcony were higher than those of the flat with a glazed balcony. The surface temperatures were significantly influenced by radiator temperatures, which during the heating season were clearly higher in the flat with an unglazed balcony than in the one with a glazed balcony. On average, the window, door, and internal wall surface temperatures of the flat with an unglazed balcony exceeded the respective temperatures of the flat with a glazed balcony by 1.0 °C, 0.4 °C, and 2.0 °C, respectively. In the flat with an unglazed balcony, the radiator heating effect was particularly evident in wall and window surface temperatures. For example, on 24th March 2010 at 1 p.m., with an outdoor temperature of 1.7 °C, the radiator surface temperature in the flat with an unglazed balcony was 40 °C and in the flat with a glazed balcony 31 °C. The radiators were located on the interior side of the balcony back wall right under the window.

5.2 IDA-ICE 4.61 simulations

Simulation results are showed in a few different ways to illustrate the real meaning of the results. At first the mean values of the simulated and measured flat and glazed balcony inside temperatures and difference between those values are described. After that mean, standard and max deviations are calculated. Mean deviation is average of all individual difference between each value in a set of, and the average of all values of that set. It tells how far, on average, all values are from the mean value. The standard deviation in turn tells how tightly all the various examples are clustered around the mean in a set of data. Max difference is maximum difference between simulated and measured values in the data.

Glazed balcony and flat indoor air temperatures

During the simulation period, the measured and simulated glazed balcony and flat mean temperatures corresponded with an accuracy of -0.08 to 0.12 °C and 0.40 to 0.42 °C, respectively, due to the simulation model detailing level (Tab. 3). The lowest mean temperature inside the glazed balcony achieved in the climate model with detailed window and the highest in the energy model with simplified window. Temperature difference
between most detailed and simplest modelling method was approximately 0.20 °C through the entire simulation period. Two-thirds (about 0.135 °C) of this change was due to the difference between climate and energy model and one-third (about 0.065 °C) of due to the difference between simple and detailed window model. The higher glazed balcony temperature means less heat loss from inside the building to the balcony and at the same time lower the energy consumption of the building. As a result, the energy saving effect of the balcony glazing will be over-estimated (Tab 4.).

Table 3. Example calculations of measured and simulated temperatures, temperature differences and standard deviation as well as mean and maximum deviations inside the glazed balcony and the flat with a glazed balcony during the whole simulation period from 17th July to 31th December 2009.

<table>
<thead>
<tr>
<th>Glazed balcony</th>
<th>Average temperature [°C]</th>
<th>Temperature difference [°C]</th>
<th>Standard deviation</th>
<th>Mean deviation</th>
<th>Max difference</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Measured</td>
<td>Simulated</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy model with detailed window</td>
<td>9.96</td>
<td>10.01</td>
<td>0.05</td>
<td>0.93</td>
<td>0.63</td>
</tr>
<tr>
<td>Climate model with detailed window</td>
<td>9.96</td>
<td>9.88</td>
<td>-0.08</td>
<td>0.94</td>
<td>0.63</td>
</tr>
<tr>
<td>Energy model with simplified window</td>
<td>9.96</td>
<td>10.08</td>
<td>0.12</td>
<td>0.94</td>
<td>0.64</td>
</tr>
<tr>
<td>Climate model with simplified window</td>
<td>9.96</td>
<td>9.94</td>
<td>-0.02</td>
<td>0.94</td>
<td>0.64</td>
</tr>
<tr>
<td>Flat</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Energy model with detailed window</td>
<td>23.35</td>
<td>23.75</td>
<td>0.40</td>
<td>0.32</td>
<td>0.26</td>
</tr>
<tr>
<td>Climate model with detailed window</td>
<td>23.35</td>
<td>23.75</td>
<td>0.40</td>
<td>0.32</td>
<td>0.25</td>
</tr>
<tr>
<td>Energy model with simplified window</td>
<td>23.35</td>
<td>23.77</td>
<td>0.42</td>
<td>0.32</td>
<td>0.25</td>
</tr>
<tr>
<td>Climate model with simplified window</td>
<td>23.35</td>
<td>23.77</td>
<td>0.42</td>
<td>0.32</td>
<td>0.25</td>
</tr>
</tbody>
</table>

+ = simulated warmer, - = measured warmer

The standard and mean deviations were at the same level in all the calculations and so the difference between calculation accuracy was not seen in these results comparisons. The largest individual differences between measured and simulated glazed balcony temperatures were measured during moments when residents left the balcony door open to air the flat (Fig. 7) and do not therefore bring further clarity on the calculation accuracy. Such large difference did not occur at apartment temperatures. As a result, the smallest maximum difference between measured and simulated flat temperatures occurred in the climate model with detailed window (Tab. 3).
Figure 7. Measured and simulated air temperatures of the glazed balcony from 5th to 7th November 2009. The temporary divergence between the measured and simulated values was registered throughout the measurement period as a result of resident habit to left the balcony door open to air the flat. One example of this is shown on 7th November 2009 at 7 pm.

Energy saving effects differs from 4.1 % to 4.9 % according to calculation method (Tab. 4). The difference between the simplest and the most detailed calculation was 0.8 % (15.7 % change in the result). A simple window structure reduced the energy consumption of both flats, but roughly the same proportion, so that it had a very limited impact on energy saving effect of the balcony glazing. Simple and detailed window models energy saving effect differs only 0.1 % (1 % change in the result). Difference between energy and climate model was greater, about 36 kWh and 0.7 % (14.7 % change in the result). This review underlines the climate model use.

Table 4. Apartments energy consumptions and energy saving effect of glazed balcony calculated with four different calculation accuracy

<table>
<thead>
<tr>
<th></th>
<th>Flat with glazed balcony [kWh]</th>
<th>Flat with unglazed balcony [kWh]</th>
<th>Energy saving effect [kWh]</th>
<th>Energy saving effect [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy model with detailed window</td>
<td>4642.2</td>
<td>4842.5</td>
<td>200.3</td>
<td>4.1 %</td>
</tr>
<tr>
<td>Climate model with detailed window</td>
<td>4631.6</td>
<td>4833.6</td>
<td>202</td>
<td>4.2 %</td>
</tr>
<tr>
<td>Energy model with simplified window</td>
<td>4630.8</td>
<td>4866.5</td>
<td>235.7</td>
<td>4.8 %</td>
</tr>
<tr>
<td>Climate model with simplified window</td>
<td>4619.9</td>
<td>4858.4</td>
<td>238.5</td>
<td>4.9 %</td>
</tr>
</tbody>
</table>
Surface temperatures inside the glazed balcony

Surface temperature data simulation yielded promising results in the most detailed calculation. For example, the window external surface temperatures of the flat with a glazed balcony corresponded to the simulated values with an average accuracy of 0.27 °C and 0.92 °C (two measurement points), and the internal temperatures with an average accuracy of 0.42 °C and 0.65 °C. Simulated values were higher than measured values in the most detailed calculation (Fig. 8), but were even warmer in another simulation. For example, the external surfaces temperatures of the window corresponded to each other with an average accuracy of 0.69 °C and 1.34 °C, and the internal temperatures with an average accuracy of 0.44 °C and 0.67 °C in the simplest calculation. As seen from the previous results, the chance in the calculation method affect only slightly to the surface temperatures of the internal surface, but significantly to the surface temperature of the external surface. For example, the change of the window external surface temperature was 0.42 °C (0.69-0.27=0.42 or 1.34-0.92=0.42) and of the internal surface temperature 0.02 °C (0.44-0.42=0.02 or 0.67-0.65=0.02). The zone model had a greater effect on the calculation results than the window model. About four-fifths of the difference cause from the differences between the climate and energy models and about one-fifth of the difference between the detailed and simplified window models. The results show clearly that the climate model with detailed window model is recommended to use in glazed space surface temperature calculations.

Figure 8. Measured and simulated external surface temperatures of the window between the flat and the glazed balcony from 5th to 7th November 2009. The surface temperature data simulation yielded promising results.
In the simulation, literature values for colour based absorption coefficients were used. Those coefficients cause generally a little warmer surface temperatures than measured ones and correspondence with measured and simulated values were better on the upper part of the structures (shaded by balcony slab) than on the lower part of the structures. One of the reasons was the fact that the unshielded surface temperature sensors on the lower part of the structures were exposed to the direct solar radiation and also to the sky radiation. As a result, these sensors warmed up strongly when the sun shines to the sensors and cooled more during the night as a reason for the higher exposure to the sky radiation. For eliminating these uncertainties, the real surface absorption coefficients would have been determined on side and the surface temperature sensors would have been protected against the direct solar radiation. The results, however, show that the reliable surface temperature values are possible to achieve with IDA-ICE, when using climate model with detailed window structure and reliable surface absorption coefficients.

**The significance of different input parameters to the model accuracy**

Parameters significance analysis shows that the importance of the detailed simulation method increases when the amount of glazing increase or external shading amount decrease (Table 5). For example, the simplest and most detailed calculation models accuracy difference changed 0.2 to 0.35, when amount of glazing altered from one to three sides of the glazed balcony and external tree shading was removed. On the other hand, the results also show that the difference between calculation results decreases when balcony inner surface absorption coefficients increase. This means that dark surfaced balconies simulation accuracy difference is very small between the most detailed and simplest modeling method.

**Table 5. Different input parameters significance to the modelling accuracy. Result shows that the importance of the detailed simulation method increases when the amount of glazing increase or external shading amount decrease and decreases when balcony inner surface absorption coefficients increase.**

<table>
<thead>
<tr>
<th>Calculation case</th>
<th>Glazed space mean temperature difference between the most detailed and simplest calculations [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Original</td>
<td>0.2</td>
</tr>
<tr>
<td>External tree shading excluded</td>
<td>0.30</td>
</tr>
<tr>
<td>Glazed side from one to three in the balcony</td>
<td>0.21</td>
</tr>
<tr>
<td>Glazed side from one to three in the balcony and external tree shading excluded</td>
<td>0.35</td>
</tr>
<tr>
<td>Absorption coefficience +0.1</td>
<td>0.17</td>
</tr>
</tbody>
</table>
The results also show that wrong input parameters can have as significant or even greater impact on the results than different modelling method (Tab. 5 and 6). For example, a change of 0.1 to the absorption coefficient causes greater effect on the calculation results (difference 0.28) than the model chance from the detailed level to simplified one (0.2). In addition, the mean and standard deviation results indicate that the current calculation contains a lot of uncertainty (Tab. 3). Critical input parameters proved to be the amount of supply air from the glazed balcony, conduction losses from the building to the balcony and from the balcony to outdoor as well as the glazed balcony airtightness and balcony inner surface absorption coefficients.

**Table 6. Mean temperatures after model changes**

<table>
<thead>
<tr>
<th></th>
<th>Measured values [°C]</th>
<th>Originally simulated [°C]</th>
<th>Absorption coefficient +0.1 [°C]</th>
<th>30 % of the external three shading excluded [°C]</th>
<th>Balcony glazing air leakage area halved (0.07m² -&gt; 0.035m²) [°C]</th>
<th>Supply air vent size doubled in the wall between apartment and balcony (0.02m² -&gt; 0.04m²) [°C]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Climate model with detailed window</td>
<td>9.96</td>
<td>9.88</td>
<td>10.16</td>
<td>9.98</td>
<td>10.13</td>
<td>9.97</td>
</tr>
<tr>
<td>Difference between original simulation and changed simulation</td>
<td>0.28</td>
<td>0.10</td>
<td>0.22</td>
<td>0.09</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Future perspective**

In planning of similar simulation studies, special attention should be paid to the selection of the measurement site and favour rather simple measurement cases than complex ones. Another important issue is to set up a small-scale weather station for measuring wind speed, wind direction, air pressure and global horizontal radiation, direct normal radiation and diffuse radiation measurement on site. The problem in this case was that the solar radiation data was measured about 80 km, wind data 20 km and one part of the outdoor temperatures and relative humidity 20 km from site. This caused the uncertainty in the calculations. The third finding was the unshielded surface temperature sensors warming up under direct solar radiation causing error to the calculation results. This error could be avoided by using shielded surface temperature sensors. The fourth finding was the importance of using measured thermal conductivity of the structures and balcony inner structures absorption coefficients. Now, the material U-values were determined by using real structure thickness and literature values for thermal conductivities. Material properties of windows and doors and U-values were from the manufacturer's product information. On this basis, the accuracy of the U-values was not absolute certainty. The fifth thing was the uncertainty of the balcony airtightness and real airflow through the balcony back wall air inlet vents. It will be
possible to get a better understanding of the operation of the ventilation system in different wind conditions, and a more accurate picture of air movement from the outside to apartment through the glazed balcony by using long term measurements to track real air flow through those structures. Sixth, it is very hard to model mixed forest accurately in IDA-ICE program. Therefore, it would have been preferable to select easier simulation site as external shading mean or set outside trees as closely as possible to the real situation after very detailed observation and measurements on site. Finally, it is very difficult to track real operation of inhabitants inside the apartment. The determination is very difficult in practice, because it is challenging to bound residents to follow instructions and if they undertake then the activity is known, but it might not be normal use of the building. Therefore, one option would be to choose a measurement site with a vacant apartment.

5.3 Simulation time
Calculation time varied between 29min 11 s and 35min 23s depending on the calculation case (Tab. 2). Difference between the slowest and the fastest calculation was 6 min 36s (difference 17.5 %). Mostly slowdown was cause by the zone model change (about 16%), but also window model change cause a minor effect on the calculation time (1.5%). Energy and climate model calculation time differs very clearly, even though a total of 14 zones were in the built simulation model (7 per apartment). In the more complex simulation models, modelling time difference will be further emphasized.

6 CONCLUSION

Temperature measurements show that the temperature of the glazed and unglazed balconies is higher than outdoor temperature almost throughout the year. On average, the temperature of the unglazed balcony was 0.8 °C, and that of the glazed balcony 3.7 °C, higher than outdoor temperature. During the heating season, the temperature differences were 0.8 °C and 4.1 °C, respectively. Temperature differences between the balconies and outdoor air varied depending on time of day and season. As outdoor temperatures decreased, the temperature difference between the glazed balcony and outdoor air increased, and vice versa. The greatest temperature difference between the glazed balcony and outdoor air was 14 °C; it was measured on 12th December 2009 at 9 p.m.
The balcony window, door, and back wall external surface temperatures of the glazed balcony exceeded those of the unglazed balcony throughout the measurement period. On average, the window, door, and wall external surface temperatures of the glazed balcony exceeded the respective temperatures of the unglazed balcony by 2.5 °C, 2.0 °C, and 1.4 °C. The temperature difference between the balconies was clearly larger during the heating season than in summertime. Internal surface temperatures of the flat with an unglazed balcony were higher than those of the flat with a glazed balcony. The surface temperatures were significantly influenced by radiator temperatures, which during the heating season were clearly higher in the flat with an unglazed balcony than in the one with a glazed balcony.

Literature review as well as comparison of the simulated and measured temperatures suggests that IDA-ICE 4.61 software is well suited for energy efficiency evaluation of balcony glazing. The highest modelling accuracy can be obtained by using a detailed window structure (Detwind) and a zone (Climate) model. Of these, the zone model had a greater effect on the calculation results than the window model. The simulation results also show that the wrong input parameters can affect as significant or even greater impact on the results than difference between model detailing levels. For example, 0.1 change to the absorption coefficient causes greater effect on the calculation results (difference 0.28) than model chance from the detailed level to simplified one (0.2). The software’s calculation accuracy depends on the correctness of the source data entered and the model detailing level. Both should be paid attention in the simulation studies.

7 REFERENCES


