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Impact of Internal Heat Gains on Building's Energy Performance

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Abstract. Internal heat gains from occupants, equipment and lighting contribute a significant proportion of the heat gains in an office space. Usage of ICT in offices is growing; on the other hand, their efficiency is also improving all the time. Increasing energy efficiency in buildings have led to the situation, when new, well insulated office buildings, with high internal gains within the working hours may cover low heating energy demand. Such buildings, even in heating dominated countries, such as Lithuania, often also suffer from overheating during the winter heating season.

The paper presents the analysis of energy demand of the office building for various plug loads (ICT equipment) internal gains scenarios and demonstrates its influence on buildings energy performance. Simulation results enable to conclude, that when assessing sustainability and energy bills of the building, plug loads play a very important role. Meanwhile, assessing just energy performance influence is very small. Energy performance certification results show, that plug loads may influence energy performance label just for buildings corresponding A+ and A++ labels).

Keywords: office, energy performance, internal gains, simulation, certification.

Conference topic: Energy for Buildings.

Introduction

EPBD requirements for energy performance of the building cause the changes of their heat balances, especially in public buildings. Energy demand caused by envelope transmission losses continues decreasing; consequently, energy efficiency of the building increases. Therefore, in energy efficient buildings, especially offices, the internal loads play a significant role in their heat balance and may influence their energy performance label. Monstvilas *et al.* (2010) states that internal loads strongly influence the determination of energy performance, where the false results may cause economic losses.

Internal heat gains in the office building arise from lighting system, directly from occupants as well as occupants related IT equipment (also called plug loads or small power). Plug loads energy consumption is very dynamic and, despite energy efficiency of IT technologies is increasing, simultaneously increases their usage. Thus, predictions of the plug loads energy consumption and related heat gains becomes a complicated issue. Some studies show, that plug loads may represent up to 50% of electricity use in buildings (NBI 2012); 6% of this consumption is caused by computers and screens (Moorefield *et al.* 2011). Inaccurate prediction of internal loads leads to inefficient building design, higher capital and operation costs (Komor 1997; Dunn, Knight 2005).

Mahdavi *et al.* (2016) showed that the observed loads in the selected office do not necessarily correspond to common assumptions in standards and simulation input data. Moreover, patterns of user presence and plug load requirements differ significantly among individual office users. Johansson and Bagge (2011) indicated that the variation in household electricity is not negligible when energy use simulations or power demand simulations are performed, particularly for low energy buildings.

Detailed methodologies, e.g. (CIBSE 2012), exist and enable a more robust prediction of power demand. Still, in practise, designers mostly rely on benchmarks to inform predictions of small power (plug loads) consumption, power demand and internal gains. These are often out of date and fail to account for the variability in equipment speciation and usage patterns in different offices (Menezes *et al.* 2014). Therefore, the methodological aspects of heat gain prediction and critique to it are discussed in different studies, which showed discrepancy between norm-based calculations and actual results (Firląg, Murray 2013; Jin, Overend 2014; Tian *et al.* 2015; Wang *et al.* 2014). In these studies, the standardized values for heat gains are predicted based on either ISO 13790 standard or ASHRAE heat balance (HB) method (it is also used in EnergyPlus simulation software). Simplified calculation method ISO 13790 for energy demand is a quasi-steady state method, which receives the most criticism. According to the standard, all types of heat gains should be used for the estimation of building heat gains, but the utilization factor of heat gains is determined without any restrictions on time (Monstvilas *et al.* 2010). Firląg and Murray (2013) state, that it can be suitable for buildings with standard energy need, but for very low-energy buildings the methodology has to be more precise. Their study shows that the difference in energy need for heating, calculated using precise and simplified methods of internal heat gains determination was 30.1%.

Overall, since norm-based modelling displays a crucial limitation in terms of its negligence of the dynamic characteristics of internal heat gains, it is important to improve the quality of energy predictions and to facilitate energy simulations that better agrees with physics and actual energy use (Elsland *et al.* 2014; Johansson, Bagge 2011).

This paper presents the analysis of energy demand of the office building for various internal gains scenarios and demonstrates its influence on buildings energy performance.

Methodology

The analysis is performed using dynamic energy simulation tool DesignBuilder (EnergyPlus interface) and national building energy performance certification tool – NRG3. Analysed building – existing energy efficient office building in Vilnius (Lithuania). Research is done following steps:

1. Simulation with DesignBuilder of existing office building (see Fig. 1 and Table 1) with different plug loads (office equipment loads). Simulations were performed for 7 cases of plug loads: 0, 5, 10, 15, 20, 25 and 30 W/m^2. Typical distribution of the office building heat gains within the working hours is shown in Figure 2 (data from DesignBuilder model).

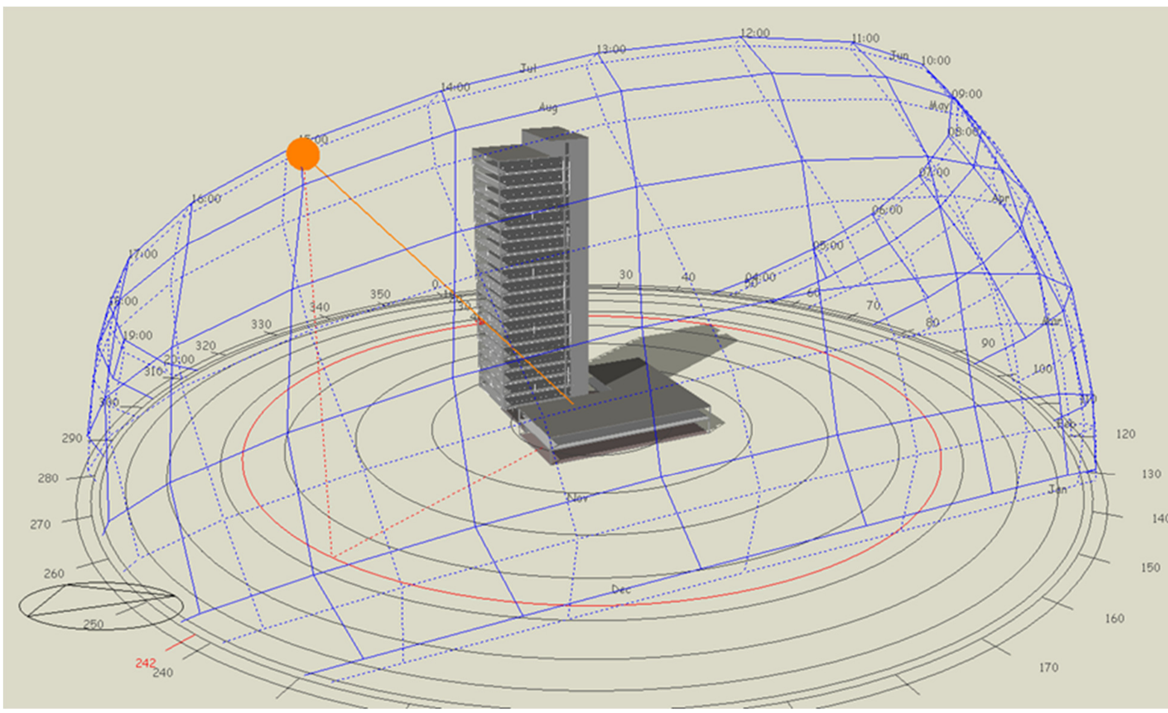


Fig. 1. DesignBuilder model of the building

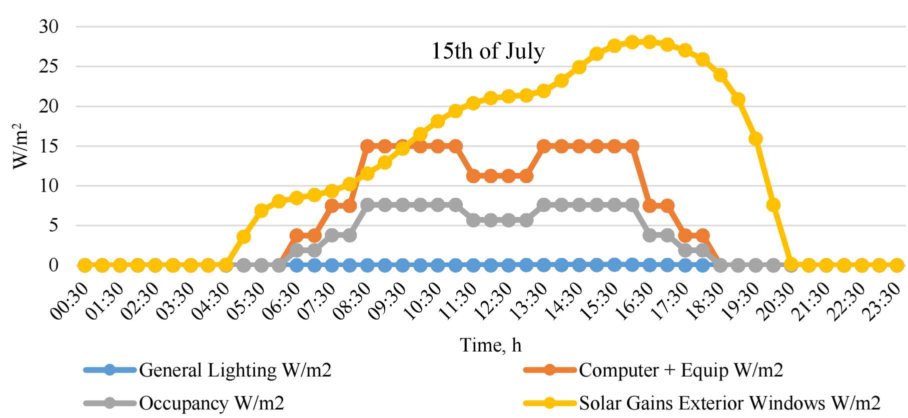


Fig. 2. Typical daily heat gains profiles, examples of summer cooling design day, when office equipment load is 15 W

Simulation assumptions:

– Power load density within unoccupied hours is equal 0.
– Internal gains work together with occupancy;
– All electricity, consumed by lighting and office equipment is converted to heat.

2. Analysis of simulation results.
3. Office building performance certification with NRG3 national tool.
4. Analysis, seeking to define if and how internal heat gains from office equipment influence energy performance label of the building.

Table 1. Main model input data

Total area, m^2	20239.18
Volume, m^3	94215.00
Number of stories	21
U-values	
Roof	$0.11\ W/(m^2 \cdot K)$
External floor	$0.12\ W/(m^2 \cdot K)$
Floor above unheated cellar	$0.10\ W/(m^2 \cdot K)$
Walls	$0.15\ W/(m^2 \cdot K)$
Windows	$0.53\ W/(m^2 \cdot K)$
Door	$1.30\ W/(m^2 \cdot K)$
Thermal bridges	$\leq 0.04\ W/(m^2 \cdot K)$ $\leq 0.10\ W/(m^2 \cdot K)$
Window solar heat gain coefficient, g-value	0.421
Window light transmission	0.484
Airtightness (at 50 Pa)	1.0
Building occupancy hours	Monday to Friday from 7:00–19:00 h
Internal temperatures	20 °C – heating season 24 °C – cooling season
Fresh airflow rates: – offices – corridors	$3.6\ [m^3/h \cdot m^2]$/ $36\ [m^3/h \cdot person]$ $1.8\ [m^3/h \cdot m^2]$
Thermal efficiency of the heat recovery	75%
Lighting system power, target illuminance	$2\ W/m^2$/100 lux, 400 lux
Occupancy density	0.111 person/m^2

Building is heated and cooled with fancoil units. Heat is produced by gas boiler, electricity is supplied from the city network.

Results

Simulation results

Annual simulation results have confirmed statement that for energy efficient building in its purchased energy balance dominates electricity. Figure 3 shows an example of the case, when plug loads are assumed to be 15 W. As it can be seen from Figure 3a, if we take into account just energy, needed to create proper indoor climate in the building, most of energy is consumed in building systems in the form of electricity. However, heat also constitutes a considerable share. But if we take a look at the structure of the energy balance taking into account also office equipment electricity (see Fig. 3b), heating share becomes relatively small. These figures show that more attention must be paid to office equipment in the building, which makes significant influence on energy bills as well as on total sustainability of the building.

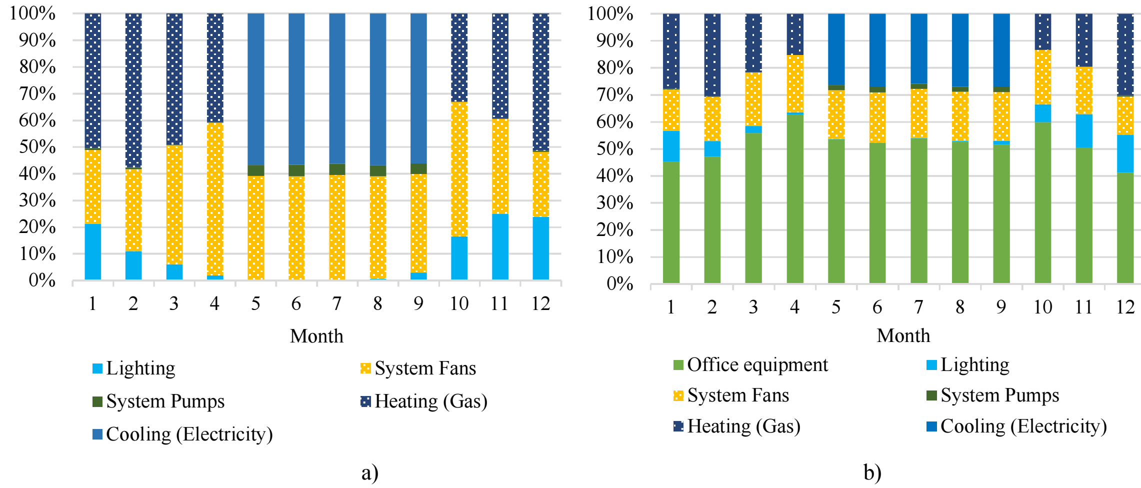


Fig. 3. Structure of the energy balance by purchased energy: a) just indoor climate systems; b) buildings total energy

Higher electricity consumption of the office equipment also means higher internal heat gains. As seen from the Figure 4, total annual heat gains of the office depending on power plug loads vary from 60 to 120 kWh/m^2, accordingly heat gains from internal heat sources are 18–78 kWh/m^2 and just plug loads (computer + equipment) – 0–71 kWh/m^2. Meanwhile results of Counsell *et al.* (2011), who analysed 3 scenarios (Energy conscious ICT, Base Case, Techno explosion); annual internal heat gains varied approx. from 38 to 110 kWh/m^2 (correspond to Techno explosion scenario, when ICT equipment power is 33 W/m^2). Mainly differences may be explained by different assumptions concerning occupants and lighting internal gains. If we compare just ICT heat gains, techno explosion scenario practically corresponds to the value gained at 30 W/m^2 (78 kWh/m^2).

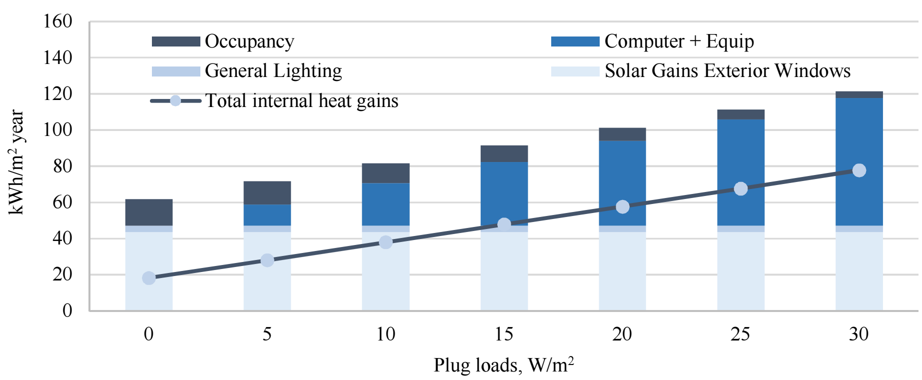
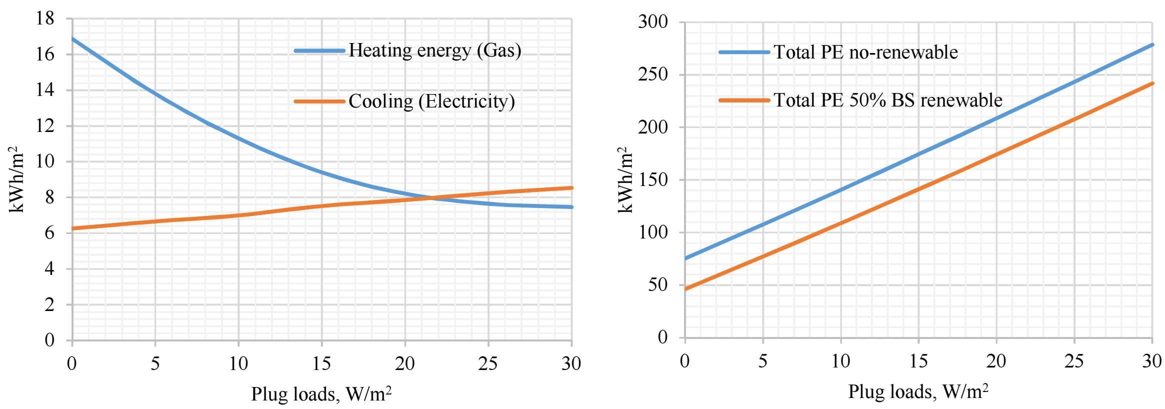


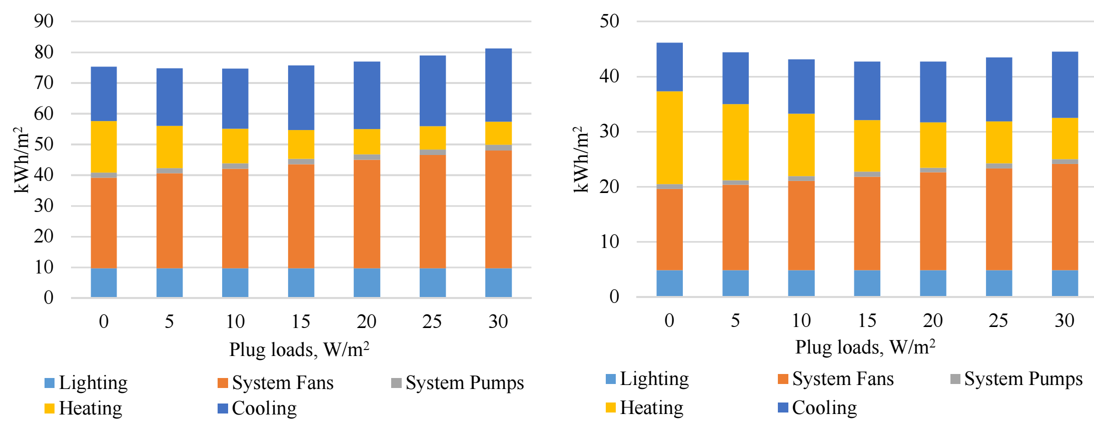
Fig. 4. Dependency of heat gains of the building on the plug loads

Figure 5a demonstrates, that plug loads of the office, make significant influence on heating and cooling energy demand and that with the increase of the heat gains, cooling energy (electricity) demand increases from 6.7 to 8.5 kWh/m^2 (by 27%). Meanwhile heating energy demand drops from 16.9 to 7.5 kWh/m^2 (by 56%). From those results, it seems that plug loads make a significant influence on energy demand of the building. However, objective assessment of the buildings envelope energy efficiency must be done in terms of primary energy and assessing all energy consumed in the building to create certain indoor climate. Such an assessment is also done by most of the building energy performance certification standards (in Lithuania as well). Total primary energy demand is shown in Figure 6a (when electricity is produced from non-renewable energy sources that is typical case in Lithuania and many other countries, assumed primary energy factor for electricity 2.8). As it is seen, when we convert energy into primary and add electricity consumed by systems pumps and fans (so called "parasitic energy") as well lighting, influence of the plug loads heat gains becomes relatively small, just 8%. If we assume, that 50% of electricity demand of building systems (BS – lighting and HVAC) is covered by solar electricity (primary energy factor 0.01), difference between cases becomes even smaller – just 4.2%. This leads to the conclusion, that influence of the plug loads heat gains on the energy efficiency of the building is small. But at the same time, this small difference theoretically may influence its energy performance label.



a) b)

Fig. 5. Influence of the plug loads on building's: a) purchased heating and cooling energy; b) primary energy demand (when HVAC energy and office equipment electricity is taken into account)



a) b)

Fig. 6. Total primary energy demand for two cases: a) when electricity is supplied from grid; b) part of electricity is produced from solar energy (PV)

With the progress of energy efficiency of the buildings, energy efficiency becomes just one of the criteria when assessing sustainability of the building, for example according to BREEAM or other popular buildings sustainability certification schemes. Therefore, it would not be correct, if we just analyse internal heat gains from the plug loads and do not include in comparison also electricity consumed to produce these gains. Figure 5b demonstrated, how plug loads influence total primary energy demand of the building (HVAC+Lighting+Office equipment). In general, it is total energy purchased by the building user, but expressed in terms of primary energy. In that case, variation in energy demand of the building, depending on plug loads heat gains is huge for both cases, when all consumed electricity is non-renewable and part is renewable. Primary energy demand may increase accordingly 2.7 and 4.2 times. It is obvious that energy efficient equipment with low plug loads in the office must be essential both for sustainability and for energy bills of the building.

Energy performance certification

The energy performance certification was done for this building using the national software tool NRG3. The software, which is created according to national certification standard STR 2.01.02:2016 "Design and certification of energy performance of buildings" where internal heat gains are evaluated according to the purpose of the building. The calculation method is based on monthly method given by ISO 13790 "Energy performance of buildings – Calculation of energy use for space heating and cooling". Internal heat gains according to NRG3 include heat gains from occupants, lighting, office equipment and heat gains from domestic hot water pipes. The value of internal heat gains for office buildings in this case is fixed and equals to 21.6 kWh/m^2 per year. This value is similar to the simulation results, when plug loads are between 0 and 5 W/m^2 (see Fig. 4). The certification result of total primary energy demand of the building is 116.55 kWh/m^2, heating demand 13.58 kWh/m^2 and cooling demand 35.54 kWh/m^2. Comparing with simulation results where total primary energy demand varies from 46.2 kWh/m^2 to 278.6 kWh/m^2, value of primary energy according to certification tool is in the gap when plug loads are between 5 and 10 W/m^2. This might be explained by methodological differences.

The certification label depends on several different factors: some of them are composite and some are direct. The direct factors have values for each label. One of direct factors is heating demand. Cooling demand has influence in the total primary energy balance and can be neglected using renewable energy sources. Therefore heating demand factor was chosen for the analysis of internal heat gains influence to energy performance label.

The analysis of internal heat gains influence on energy performance label was done by changing building's purpose (cases a-b in Fig. 7), because standard gives fixed value according to the buildings purpose and it cannot corrected in the other way. The calculated label of analysed object was found to be A. The results with different internal heat gains values are shown in Figure 7. It is seen, that for an analysed building, the label did not change, because value of heating energy demand was in the middle of A label boundary. Change of internal heat gains more than 4 times, did not change the label, but if internal gains have not been evaluated at all, the label would be B.

Results show, that evaluation of internal heat gains can affect the energy performance label directly, when value of heating energy demand is closer to label boundary. Also in the case of more efficient buildings. Analysing A+ and A++ buildings, where heat gains have higher share in total building's energy balance, the influence of internal heat gains on energy performance label would be higher. Otherwise, for B and lower energy performance label buildings internal heat gains will make lower impact.

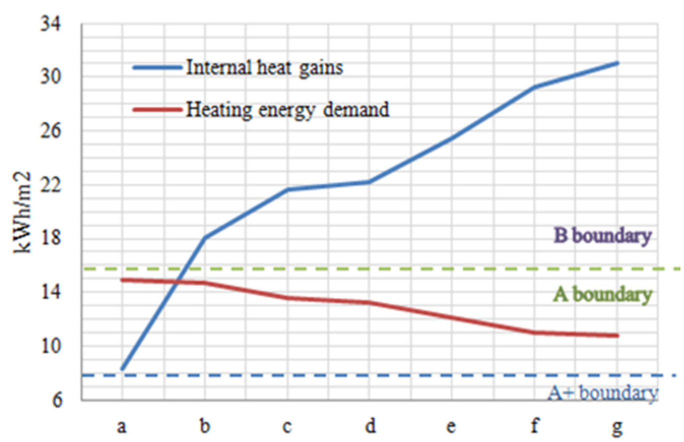


Fig. 7. Dependency of internal heat gains and heating energy demand, which affect the energy performance label.
Note: a, b, c and etc. show different cases, which are created by changing building's purpose and A, B and C mean energy performance label

Analysis shows that used certification standard does not evaluate so much office equipment as was simulated in described case. Comparing results of internal gains (Fig. 4 and Fig. 7) it is seen, that certification tool evaluated not more than 5 W/m^2 of plug loads gains.

Discussion and conclusions

Annual simulation results have confirmed statement that for energy efficient office building in its purchased energy balance dominates electricity. Total annual heat gains of the office depending on power plug loads vary from 60 to 120 kWh/m^2, accordingly heat gains from internal heat sources are 18–78 kWh/m^2 and just plug loads (computer + equipment) – 0–71 kWh/m^2. Plug loads of the office, make significant influence on heating and cooling energy demand: with the increase of the heat gains, cooling energy (electricity) demand increases from 6.7–8.5 kWh/m^2 (by 27%). Meanwhile heating energy demand drops from 16.9–7.5 kWh/m^2 (56%). If assessment is performed in terms of primary energy taking into account all energy consumed by building indoor systems (HVAC+lighting), influence of plug loads heat gains drops to 4.2–8%. This leads to the conclusion that for analysed energy efficient building influence of the plug loads on its energy performance is relatively small. But if we take into account also electricity consumed by office equipment, primary energy demand varies accordingly 2.7 and 4.2 times. Therefore, it is obvious that energy efficient equipment with low plug loads in the office must be essential both for sustainability and for energy bills of the building. It must be forecasted as precise as possible and designer or performance assessor of the building should give recommendations to users on efficient office equipment. Spatial attention must be paid to computers and their monitors, because according to literature review, they consume 66% of total office equipment electricity.

Energy performance certification should be used to inform about the building and it shouldn't be very accurate, comparing with simulation results. But the requirements for the buildings are tightening every 2 years. The more tight and insulated is the building, the higher influence of heat gains appears. The analysis showed that for the building with higher energy performance label than A, results of the energy performance certification become more sensitive to internal heat loads. Therefore, they must be assessed more accurately and certification standard must be more flexible, enabling to assume more realistic values of internal heat gains, especially related to plug loads.

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