401: Effect of Internal Gains on Thermal Comfort in Welsh Dwellings

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Abstract

This paper investigates the role of the energy released by appliances and lighting on the heat balance of dwellings. This is studied in the context of building simulations, used for the prediction of temperature, energy demands and thermal comfort assessment of houses. For this study, 12 typical housing types, considered as representative of the entire Welsh Housing Stock, are used. The models' input is based on generic housing data for Wales and recent "representative" European Domestic Electrical Consumption profiles. All the cases are compared against a reference model per dwelling, with no gains due to appliances and lighting. The annual energy demand required to maintain thermal comfort conditions for each model is calculated and the portion of it met solely by the energy output of the appliances and lighting is identified for all models. The results show the contribution from internal gains to the heating and cooling demands in the Case Study housing, the potential error range which exists in the predictions from using only average profiles, compared to real consumption patterns and the range of the demand profiles per house type, which is important for future studies regarding low energy and low carbon heating and cooling applications.

Keywords: Internal gains profiles, thermal comfort, prediction, modelling

1. Introduction

For recent housing types it is clear that the internal gains caused by appliances and lighting can have a strong effect on the annual heating or cooling load, thus affecting significantly the annual delivered heating or cooling energy in these houses. The aim of this work is to reveal the importance of using appropriate (realistic) internal gains profiles when designing and sizing systems for thermal comfort in a range of housing from different eras. This can be of critical importance when renewable energy sources or CHP are considered, as in these cases the design of the system to meet the correct load has an important effect on the overall annual energy efficiency of the system.

2. Background

2.1 Standard non-HVAC Electric Load profiles

As a result of the Subtask A of the FC+COGEN-SIM *"The Simulation of Building-Integrated Fuel Cell and Other Cogeneration Systems" Annex 42 of the International Energy Agency Energy Conservation in Buildings and Community Systems Programme"* standard European and Canadian non-HVAC Electric Load Profiles have become available. [1]. The European non-HVAC Electric Energy Consumption Profiles of this study which have been suggested as "a good first estimate of domestic electrical energy consumption profiles for many European countries" are based on the UK domestic profiles monitored by the EETS Ltd and the Welsh School of Architecture [2]. Using this data to simulate the internal gains due to appliances and lighting for the Welsh housing stock can therefore be considered the most accurate and realistic approach available for this purpose. The Subtask provides a Standard Average and 3 Actual profiles of low, medium and high consumption in domestic properties. In this paper all these 4 profiles are used to ensure that the likely extremes of internal gains from electrical demands are taken into account both at a daily and annual basis.

2.2 Welsh Housing Stock Survey (STACS)

The typical housing types used in this study are drawn from generic housing data for Wales taken from the STACS project [3].

Table 1: 12 typical dwellings of Wales (STACS)

No	Dwelling type	area (m^2)
1	Pre-1850 Detached House	87.27
2	Pre-1850 Converted Flat	103.52
3	1850-1919 Semi Detached House	220.09
4	1920-1944 Semi Detached House	93.32
5	1945 - 1964 Low-rise Flat	65.74
6	1945-1964 Semi-detached House	89.17
7	1965-1980 Detached House	116.72
8	1965-1980 Mid-terrace House	105.42
9	1981-1999 Low-rise Flat	44.70
10	1981-1999 Mid-terrace House	55.82
11	2000-2006 Semi-detached House	74.92
12	Post-2006 High-rise Flat	57.47

This selection is believed to give a good approximation of the entire Welsh Housing Stock. Materials and geometry data for the 12 dwelling types shown in Table 1 are provided by the survey.

2.3 Thermal Comfort

Ideally the thermal comfort modelling would be based on Adaptive Comfort Theories for dwellings, however little evidence is yet available to support these in dwellings [4]. The approach taken in this paper is therefore to use the values suggested by CIBSE [5].

3. Methodology

3.1 TRNSYS software package

For the simulations conducted in this study, the software package TRNSYS (version 16.01.0002) is used [6]. The software has a modular structure with a main visual interface known as the TRNSYS Simulation Studio. There is also a dedicated interface for the multizone building component (TRNBuild) which is one of the most complex models in TRNSYS. The building component of TRNSYS has undergone testing under the ANSI/ASHRAE Standard 140 and IEA BESTEST with acceptable results. Validation tools have been also used during the development of the software [7,8]. To illustrate the aims of this paper the twelve dwellings are simulated in TRNSYS (the input is discussed in detail at the following paragraphs). All the cases are compared against a reference model per dwelling, with no gains due to appliances and lighting. The annual energy demand required to maintain thermal comfort conditions for each model is calculated.

3.2 Weather data

To account for the likely extreme weather conditions (as peak demands are also of interest in this analysis), one year data taken from actual measurements from a weather station located at the roof of the Welsh School of Architecture during year 2007 was used in this study [9]. The data is recorded in 5 min intervals. This data was used in preference to TRY data which provides an average weather file for the year.

3.3 Thermal Comfort Requirements

The heating and cooling demands of each modelled zone are calculated assuming a 100% efficient heating and cooling system is in operation. The system adjusts the zone temperature according to the thermostat settings which have been set to satisfy thermal comfort requirements for the occupants. Table 2 shows the recommended temperature settings suggested by CIBSE [5], based on stated values of met and clo and a PMV of ±0.25.

Table 2: Thermal comfort requirements according to CIBSE guide A (table 1.1, 1-3).

room type	Winter dry resultant temperature range for stated activity and range clothing levels			Summer dry resultant temperature range for stated activity and clothing levels		
	Temp.	Activity	Clothing	Temp.	Activity	Clothing
Dwellings:	(°C)	(met)	(clo)	(°C)	(met)	(clo)
bathrooms	26–27	1.2	0.25	26–27	1.2	0.25
bedrooms	17–19	0.9	2.50	23–25	0.9	1.20
hall/stairs/landings	19–24*	1.8	0.75	21–25*	1.8	0.65
Kitchen	17–19	1.6	1.00	21–23	1.6	0.65
living rooms	22–23	1.1	1.00	23–25	1.1	0.65
toilets	19–21	1.4	1.00	21–23	1.4	0.65

Where specifically indicated (*) a more tolerant thermal comfort requirement (±0.5 PMV) was used in the calculations of the thermal comfort conditions. These temperature bands were used as thermostat settings in the 12 models.

3.4 Internal Gains

It is assumed that all houses are occupied by 2.4 inhabitants, which is the average occupancy for the area [10]. It has been shown that the use of the internal gains profiles are relatively similar between social and total occupant groups despite the social housing group not having a very defined occupancy profile on average The rationale used to set the occupancy patterns during weekdays and weekends is rather simple. For the non-sleeping period, during a typical weekday the house is occupied between 07:00 to 08:00 and 17:00 to 23:00, and in the weekend between 07:00 to 23:00. The gains from occupancy during these intervals are distributed over the living zones with area-based factors. The activity used is the same for all the zones and it is considered to be an average of "Standing, Light work or working slowly" (total heat output 185 Watts per person). For the sleeping period, taken to be 23:00 to 07:00, the gains (100 Watts per person) are evenly distributed over the bedrooms.

For the internal gains due to appliances both the Average Standard profile and the three specific profiles provided by Annex 42 are used. It has to be mentioned here that these profiles are based on measurements obtained from dwellings of the social sector. Nevertheless further research has shown that the daily electrical consumption profiles are relatively similar between social and total occupant groups despite the social housing group not having a defined occupancy profile on average [11].

For the purposes of this study the internal gains due to appliances both the Average Standard profile and the three specific profiles provided by Annex 42 are used. All 4 profiles have been 're-built' to be compatible with the year 2007 actual weather data used in the simulations. Table 3 shows the characteristics of the 6 different profiles which were used in this study.

Table 3: The 4 electrical consumption profiles due to appliances and lighting used in the models.

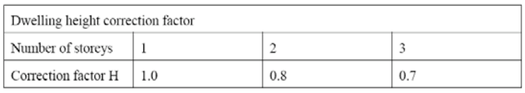
File Name	Annual Consumption [kWh]	Year	Size of dwelling [m²]	Occupancy type (as in annex 42)
Actual low	1155 (1179 for 2007)	2005	65	Single male
Actual med.	3028 (3126 for 2007)	2003	65	Mother and two children
Actual high	8387 (8765 for 2007)	2005	108	Mother and 5 children
Stand. med	3242	2007	na	na

According to a Canadian survey included in the study of Annex 42 as mentioned above these gains are caused by two groups of appliances [11]. Almost half of the gains are caused by the 6 major appliances (dishwasher, clothes washer, tumble dryer, range, fridge and freezer) which are normally found in the kitchen zone. The remaining part of the gains is caused by lighting (7.9 KWh/m^2 p.a.) and the smaller appliances. The exact share of gains assigned to each group varies between models as it depends on the floor area (due to lighting). The share caused by lighting and the small appliances is distributed evenly over the zones of each dwelling (even in stores and utility rooms) according to volume-based factors. The share caused by the 6 major appliances is added to the kitchen zone for all the building models of this study.

3.5 Infiltration and Ventilation Rates

According to ASHRAE the heat losses due to infiltration account for around 20-50% of a building's thermal load [12]. Unfortunately there are no typical or measured infiltration rates available for the building types used in this study. Information about air leakage of UK dwellings is available from two sources. An infiltration study of British Gas is based on measurements on 200 dwellings and a study conducted by BRE is based on measurements in 471 dwellings [13]. Both studies use the fan pressurization method (or "blower door method") [14]. The results of the tests described by Stephen show in general that the air leakage rates variation across the whole database is very wide, hence the author concludes that it is *"currently impossible to make a realistic estimate"* of the infiltration of a dwelling without carrying out measurements. Both studies reveal that there are some general trends relating the date of built of the dwellings and the air leakage rates but the variation of the air leakage rates is significant even within these categories and no general rule relating infiltration and age of dwelling can be driven from this study. Furthermore the BRE study reveals that although there are some clear trends identified from the sample relating certain aspects of the building (e.g. construction materials of walls and floors or window types) to the infiltration, the air leakage caused from "known" sources of leakage accounts only for 29% of the total infiltration and the remaining 71% is put down to "confounding" factors such as little cracks anywhere on the building envelope. For the purposes of this paper the average air leakage rate found by the BRE study is used (13.1 ACH_{50}). To calculate the infiltration rate under normal conditions the "divide by 20" rule is used, along with the corrections for building height which are shown in Table 4 [15,16]. No correction due to shielding and weather has been used here, as such information is not available for this database nor for the climate of Cardiff. The infiltration rates used in the 12 models can be seen in Table 5.

Table 4: Correction for the normalised leakage calculated from rates in ACH_{50} suggested by Sherman.



Dwelling height correction factor			
Number of storeys	1	2	3
Correction factor H	1.0	0.8	0.7

The whole building ventilation rates used in the models are based on the ANSI/ ASHRAE Standard 62.2-2007 [17]. The minimum whole building ventilation rates suggested by the standard are derived by Equation 1. These include a default infiltration rate of 10L/s per 100m^2. The standard also defines that if a higher infiltration rate applies then the minimum ventilation rate can be decreased by half of the excess of the known infiltration rate. For bathrooms and kitchens the continuous ventilation rates suggested by the same standard are used and it is 10 L/s and 5 ACH respectively (AHSRAE tables 5.1, 5.2). Table 5 shows the ventilation rates used for the various zones of the house as calculated in relation to the average infiltration rates for these houses.

Equation 1

$$Q_{fan} = 0.05A_{floor} + 3.5\ (N_{br} + 1)$$

Where,
Q_{fan}=fan flow rate. L/s
A_{floor}=floor area, m^2
N_{br}= number of bedrooms; not to be less than one.

Table 5: Calculated infiltration and ventilation rates for the 12 house types.

dwel	Infiltr	Vent_ house	Vent_ Bath	Vent_ WC1	Vent_ WC2	Vent_ Kitch
1	0.82	0.11	1.67	NA	NA	4.18
2	0.82	0	1.65	NA	NA	4.18
3	0.94	0	1.89	3.59	2.85	4.06
4	0.82	0.11	3.41	8.25	NA	4.18
5	0.82	0.17	2.48	NA	NA	4.18
6	0.82	0.04	5.1	9.1	NA	4.18
7	0.82	0.05	2.38	3.52	NA	4.18
8	0.82	0	3.64	6.87	NA	4.18
9	0.82	0.06	2.23	NA	NA	4.18
10	0.82	0.13	4.09	NA	NA	4.18
11	0.82	0	3.5	6.89	NA	4.18
12	0.94	0	3.22	NA	NA	0.7

4. Results

4.1 Annual demands

The results of the simulations show the range of the demand profiles per house type, which is important for future studies regarding low energy and low carbon heating and cooling applications. The results of the 3rd and the 12th model are analysed here, as an example of two extremes with regards to the overall annual energy requirement for space heating and cooling. The 3rd model is the 1850-1919 Semi Detached House and is the largest dwelling in this database. Mainly due to the high volume and the low insulation levels of the building envelope, the impact of these gains on the overall space heating and cooling load is relatively small compared to other factors e.g. fabric, ventilation and infiltration.

Table 6 summarises the total annual loads for the reference case and for the cases with Actual Low, Standard Average and Actual High gains due to appliances and lighting.

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Table 6: Space heating for the 12 models with: no gains, Actual Low, Standard Average and Actual High gains added.

House type	No gains (kWh)		AcLo (kWh)		StAv (kWh)		AcHi (kWh)		Max diff (kWh)	
	H	C	H	C	H	C	H	C	H	C
1. Pre-1850 Detached House	9538	13	8766	38	7503	107	5499	2245	4039	2232
2. Pre-1850 Converted Flat	20010	462	19160	544	17640	670	14650	1764	5360	1302
3. 1850-1919 Semi Detached House	39430	155	38410	169	36580	190	32510	551	**6920**	**396**
4. 1920-1944 Semi Detached House	16450	314	15600	335	14070	368	11030	917	5420	603
5. 1945 - 1964 Low-rise Flat	8097	80	7327	156	6023	320	3879	2295	4218	2215
6. 1945-1964 Semi-detached House	12010	164	11270	239	9991	384	7937	2420	4073	2256
7. 1965-1980 Detached House	14110	126	13340	168	12000	236	9584	1560	4526	1434
8. 1965-1980 Mid-terrace House	13560	279	12750	318	11340	383	8598	1236	4962	957
9. 1981-1999 Low-rise Flat	3847	206	3186	355	2188	737	1233	4436	2614	4230
10. 1981-1999 Mid-terrace House	5667	161	4953	238	3786	416	2195	2946	3472	2785
11. 2000-2006 Semi-detached House	10620	10	9734	31	8304	53	6223	2237	4397	2227
12 Post-2006 High-rise Flat	2943	21	2275	84	1298	365	530	3908	**2413**	**3887**

Therefore the maximum variation of 6920 kWh, caused by including or not the gains due to appliances and lighting, is low compared to the total average consumption for this dwelling which is 36,580kWh p.a. On the other hand, the 12th model is a modern new-built high rise flat, constructed according the latest insulation standards, with small room volumes. For this model, the electrical consumption due to lighting and appliances plays a major role on the total annual energy requirement for thermal comfort satisfaction. In the High gains scenario the overall cooling demand is much higher than the heating one. The same applies to the 9th and 10th models of this database. This is of critical importance for a Northern European climate where no cooling systems are traditionally used. It is apparent that for the new-build, small dwellings the expanding number of appliances used by the occupants on a daily basis is partially responsible for the increasing cooling requirement.

To identify general trends for the category that each house represents Figure 1 and Figure 2 show the same results in kWh per m^2 of space heated and cooled respectively. It is shown that between the reference case and the extreme case (model with the Actual High gains included) the difference in the thermal requirement lies within the range of 31.5-64.2 kWh/ m^2 for the whole database. Nevertheless the same comparison but with regards to the cooling demand shows a greater variation within the database, with the difference ranging between 2 - 95 Kwh/m^2. By looking at Figure 2 the conclusions derived above with regards to the models 9, 10 and 12 are confirmed. For these models the gains due to appliances are a major share of the gains/losses balance and therefore the use of the Actual High gains profiles in these models results in relatively high cooling demands.

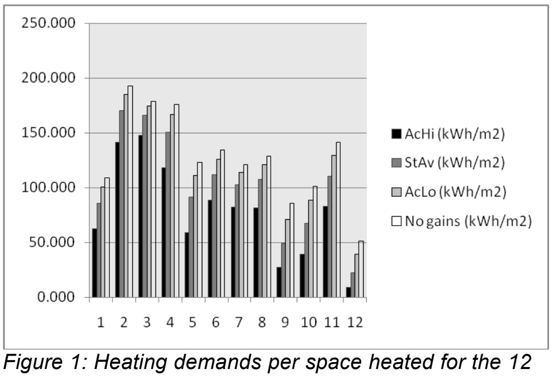

Figure 1: Heating demands per space heated for the 12 dwellings and for 4 different types of gains.

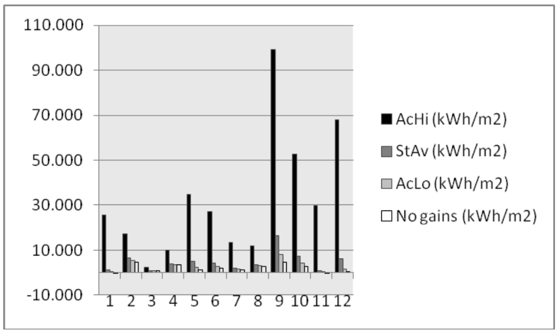

Figure 2: Cooling demands per space cooled for the 12 dwellings and for 4 different types of gains.

4.1 Peak demands

Although the overall heating and cooling demands determine the total energy consumption of the dwellings and hence the impact on carbon emissions released for this reason, the actual size of the space heating and cooling system to be used in these dwellings depends on peak heating and cooling demands. The interest here is to identify the potential error range which exists in the predictions from using only average profiles, compared to real consumption patterns.

The results show that if the two extreme profiles are used for the 12 models (Actual High and Actual Low gains) the maximum difference in peak demands is 0.61kW (3rd model) with an average value of 0.29kW within the whole database. Figure 3 shows that the actual size of the heating system required for each of the house types of the database will not change significantly if Low, Medium or High profiles, actual or average, are used in the predictions.

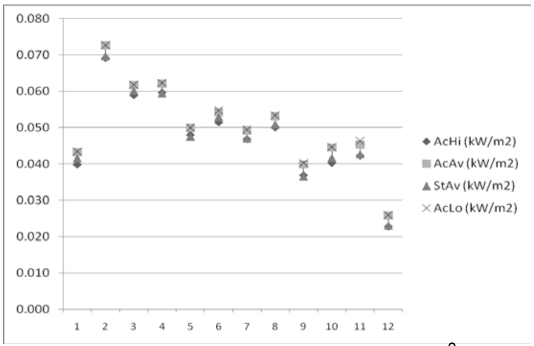

Figure 3: Peak heating demands in kW/m^2 for the 12 house types and for a range of Internal Gains profiles

Nevertheless the analysis reveals that regarding the cooling mode the findings are different. Figure 4 shows that if a wrong assumption regarding the gains due to appliances and lighting is used in the simulations, the predicted cooling system can be seriously oversized or downsized. In addition the results show that the impact of the use of the average medium profile on the prediction of the peak cooling demand of each of the 12 house types is similar to the impact of the Actual low profile. In the predictions, the use of the correct actual profile would ensure that the likely extremes of internal gains from electrical demands are taken into account both at a daily and annual basis and the proposed cooling system will operate effectively.

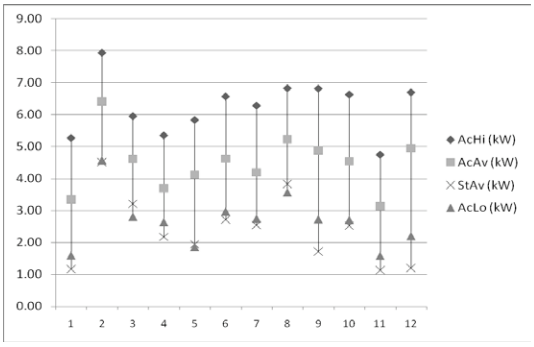

Figure 4: Peak cooling demands (kW) for the 12 models and for a range of Internal Gains profiles

4.3 Case Studies analysis

The first part of this section shows the contribution from internal gains to the heating demands of the 3rd and the 12th model. Figure 5 and Figure 6 show the share of the heating demand (as calculated for the reference case, no gains) met by the internal gains, with 3 types of profiles used; actual high, low and medium. For the 3rd model the internal gains can reduce the heat load up to 26.3% in June while for the 12th model the reduction ranges within 75.5%-99.6% , depending on the month.

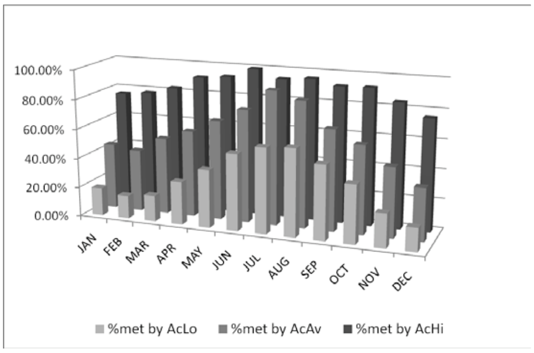

Figure 5: Share of the monthly heating demand of the dwelling No 12 met by the internal gains.

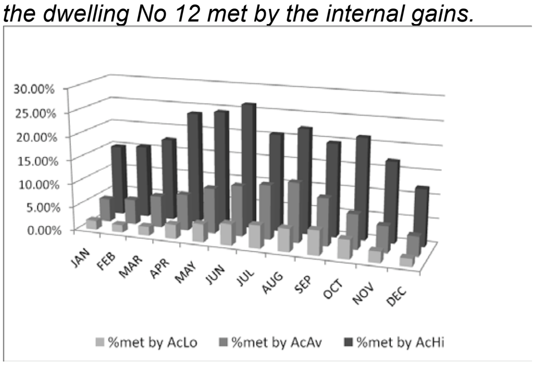

Figure 6: Share of the monthly heating demand of the dwelling No 3 met by the internal gains.

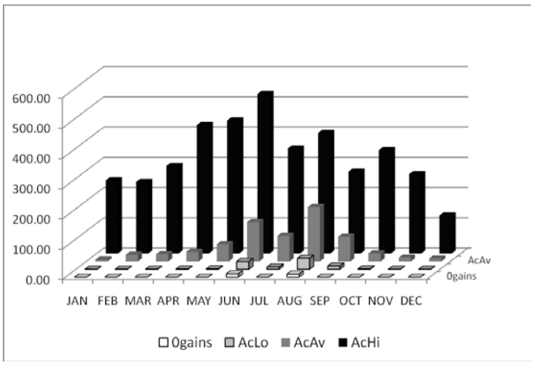

Figure 7: Internal Gains' impact on the cooling demand (vertical axis in Wh) for the Post 2006 high rise flat

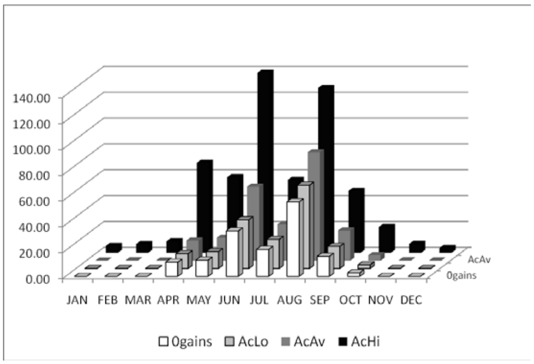

Figure 8 show the impact of the use of the three actual profiles on the cooling demand for models 3 and 12, compared to the reference case for each model. It is clearly shown that the post-2006 flat is more sensitive in the changes of the internal gains than the 3rd house type.

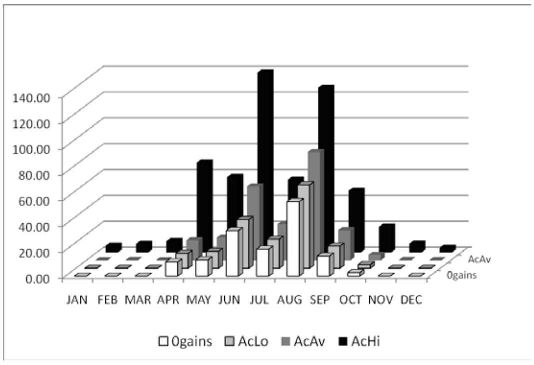

Figure 8: Internal Gains' impact on the cooling demand (vertical axis in Wh) for the 1850-1919 Semi detached house

5. Conclusions

This paper has shown that in building simulations, used for the prediction of temperature, energy demands and thermal comfort assessment of houses, the energy released by appliances and lighting has to be simulated with a realistic way, in order to ensure that the correct energy consumption is predicted and a sufficient but not oversized heating/cooling system is proposed. Especially for the new-built high rise flats a significant share of the total heating demand can be met solely by the gains due to lighting and appliances. For the summer months these gains can result in a high cooling requirement for these dwellings. This explains partially the increase in the market for domestic air conditioning systems in this country.

It is noted that only the variation of internal gains due to lighting and appliances has been assessed in this study. Future work could test occupancy variations and investigate the derivation of realistic occupancy profiles based on the European Domestic Electrical Consumption profiles of Annex 42.

6. Acknowledgements

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