Evaluation of Heat Gains in UK Office Environments

Ian Knight B.Sc., Ph.D.

Gavin Dunn B.Sc., M.Sc., M.B.Eng.

Centre for Research in the Built Environment

The Welsh School of Architecture

King Edward VII Avenue

Cardiff CF10 3NB

Wales, UK

SUMMARY

This paper presents figures for the internal loads encountered by the Welsh School of Architecture in UK offices while undertaking a programme of research and monitoring into the energy efficiency of air-conditioning systems in 'real world' Offices. The findings are based on surveys undertaken in 30 air-conditioned offices between April 2000 and October 2002.

The findings show that the common practice of using the upper limit design guidance for internal gains from current standards would lead to the overestimation of internal heat gains in all the Offices studied, in most cases substantially. The results show that a clear pattern of internal heat gains emerged which would allow a more accurate estimation of internal heat gains based on occupant density. In the light of forthcoming legislation, the findings could have major implications for sizing building services in the UK.

INTRODUCTION

This paper presents findings from an assessment of internal heat gains 'as found' in actual UK Office buildings, based upon building surveys undertaken as part of a larger research project studying the energy efficiency of air conditioning and heat-pump systems in UK offices (1)(2). Although part of a larger study, this paper only considers internal heat gains resulting from occupancy, lighting and small power gains. The calculated internal gains 'as found' are compared to current guidance and standards for building services design. The fabric and solar heat gains will be addressed in a future planned paper.

The internal loads presented in this paper are calculated from 30 standard air-conditioned office buildings (Econ 19 Type 3 (8)) and are drawn from comprehensive surveys of the buildings, their occupancy and services. The surveys were typically conducted on a single visit to each site between April 2000 and October 2002. However, most sites were visited regularly as part of a concurrent energy-monitoring programme, which enabled the survey information to be verified on a number of separate occasions ensuring the information was 'typical' for each building and not just the day on which the original survey was conducted. The original survey information has therefore been enhanced to allow a more confident assessment of the 'average' conditions found in each office.

Internal heat-gains have been calculated for each office studied using the CIBSE nameplate-ratio method(3) assuming worst-case power demand and full occupancy in order for the calculated gains to represent likely maximum gains, and therefore be comparable to loads calculated in the sizing of building services plant. These calculated loads are compared to rules-of-thumb for building services design (4) and government guidance on small power loads within offices (5).

It is intended that the information presented in this paper will add to the on-going debate regarding the levels of heat-gains within UK buildings and the relevance of current standards and guidance available to the industry. It is not intended to be a comprehensive study of this issue. Once further results are obtained from this research the results will be expanded to include fabric and solar loads encountered at the same sites.

The Welsh School of Architecture at Cardiff University has carried out this research, in association with Toshiba-Carrier UK Ltd., the Carbon Trust's Action Energy Programme and the Resources Research Unit at Sheffield Hallam University. The work has also contributed to a research programme undertaken by National Grid Transco and the Electricity Association looking at the effect of growth in the UK Air conditioning market on the national grid.

OVERVIEW OF SURVEYS UNDERTAKEN

The surveys were based upon CIBSE TM22: an energy assessment and reporting methodology for offices(6), and conducted using a format developed for the UK Non-domestic building stock data base(7). Although this paper only considers the assessment of internal heat-gains from building occupancy, lighting and small power equipment, the surveys were more comprehensive aiming to establish detailed knowledge of the following issues at each site;

- Building identity and categorization
- Building structure and layout
- Building occupancy levels and patterns
- Type and details of HVAC systems
- Building and plant history

ID Code	Type of space	Description
OP	Open Plan	Predominantly open plan often w/ some small cellular
SC	Small Cellular	Single occupancy cellular office
LC	Large Cellular	Multi occupant cellular office
CC	Call Centre	Large open plan with uniform high density occupancy
M	Mixed	Mixed open plan and cellular spaces

Table 1: Categorisation of office space

Levels of occupancy, lighting and small power were assessed by a walk-through survey of a representative office space within each building, which recorded details of the following; Number of personnel, Type and quantity of lighting fixtures, Type and quantity of office equipment.

The area of this representative space surveyed and its types of layout i.e. open plan or cellular were recorded and characterized as shown in table 1.

Assumed Lamp Ratings	
Description	**Rating**
	(Watts)
Compact Fluorescent 2 tube	11
Compact Fluorescent 4 tube	18
Fluorescent 36mm 2 foot	18
Fluorescent 36mm 4 foot	36
Fluorescent 36mm 5 foot	65
Fluorescent 36mm 6 foot	72

** Source: Sheffield Hallam University*

Table 2: Assumed lamp ratings

Wherever possible actual ratings of lamps used in the electrical lighting were recorded during the survey. However, often this information was not available or uncertain. Where lamp ratings were not obtained values have been assumed based upon the values used in the UK Non-domestic building stock database (8), the relevant assumed values are summarised in table 2.

The findings from the surveys are summarised in table 3, which shows the type of office layout; the area of the representative space surveyed; number of people; type, quantity and assumed ratings of lighting; type and quantity of office equipment found in the sample space for each of the buildings surveyed.

Survey Observations													
General			**Occupancy**	**Lighting**				**Small Power**					
Site Number	**Spatial Layout**	**Sample Floor Area** *(m^2)*	**Number of People**	**Lighting Fixtures**	**Lamps per Fixture**	**Lamp Rating** *(Watts)*	**Other Lighting** *(Total Watts)*	**Desktop Computers**	**Laptop Computers**	**Printers**	**Photo Copiers**	**Fax Machines**	***Desk Fans***
1	M	738	60	192	4	18	0	48	26	8	3	3	3
2	OP	126	20	32	4	18	0	15	5	3	1	1	1
3	LC	56	6	13	1	100	0	6	1	2	1	1	1
4	M	487	66	132	3	27	0	90	0	6	1	0	5
5	OP	140	8	40	2	20	0	4	4	2	1	0	1
6	OP	354	57	56	1	70	652	57	1	10	2	4	7
7	OP	427	76	34	3	40	0	76	5	4	2	2	5
8	LC	104	6	16	3	20	0	6	2	3	1	1	3
9	LC	31	4	8	4	36	0	4	2	1	0	0	0
10	OP	1195	178	112	2	36	738	178	50	3	3	3	1
11	OP	56	4	12	4	18	0	4	0	1	0.25	0.25	1
12	OP	765	42	120	2	36	2100	42	5	2	4	2	2
13	OP	600	51	78	1	65	0	51	10	8	1	1	0
14	CC	124	26	24	3	18	0	26	0	2	0.25	0	2
15	LC	68	4	16	1	65	0	5	1	2	0	1	1
16	LC	33	3	6	3	18	0	3	0	1	1	1	1
17	OP	450	55	72	3	36	0	53	3	3	1	1	4
18	OP	75	7	12	3	36	0	7	2	1	0.2	0.2	1
19	LC	13	3	3	2	58	0	3	0	1	0	0	1
20	LC	17	5	4	2	58	0	5	0	1	0	0	1
21	OP	944	88	188	3	18	0	88	20	10	2	1	5
22	OP	508	83	88	4	18	0	86	10	5	2	2	0
23	OP	84	8	12	2	36	54	6	2	1	0.1	0.25	3
24	OP	54	12	18	2	58	200	12	0	2	0.25	0.25	1
25	OP	56	8	8	1	65	0	8	2	1	0.2	1	3
26	OP	52	12	16	2	18	0	12	4	1	0.1	0.1	3
27	OP	52	12	16	2	18	0	12	4	1	0.1	0.1	3
28	OP	52	12	16	2	18	0	12	4	1	0.1	0.1	3
29	OP	56	10	8	3	18	0	10	6	0.5	0.25	0.125	2
30	OP	84	9	6	3	72	0	9	2	2	0.25	0.2	0

**Note: Sites 26, 27, & 28 are standard fit-out with different buildings with a single complex under the same ownership.*

Table 3: Survey Observations

CALCULATION OF HEAT GAINS

Internal heat-gains within each space studied have been calculated using the CIBSE nameplate-ratio method (3). In order for the calculated gains to represent the likely maximum gains, and therefore be comparable to loads used in the sizing of building services plant, worst-case power demand and nameplate ratios, as well as full occupancy without diversity factors have been assumed.

The calculated peak total internal heat gain is the sum of the maximum calculated gains from the; occupancy, lighting and small power components and therefore defined as follows:

Total Internal Gains *(W)* = Occupancy Load *(W)* + Lighting Load *(W)* + Small Power Load *(W)*

The calculations for the individual components are detailed below.

Normalisation of calculated heat gains:

In order to make comparisons between the different buildings surveyed and published benchmark standards the calculated internal loads have been normalised against treated floor area (TFA) and nominal occupancy levels.

The sample floor areas recorded in the survey are of typical office areas only, which do not include circulation and other service areas, or in other words net-floor area (NFA). However, treated floor area (TFA) is more representative of the entire building and is the reference area for the benchmark comparisons used in this study. Therefore, in normalising the calculated internal heat gains in this study by floor area, the sample floor areas are first converted into equivalent treated floor areas (TFA) using the benchmark assumption that TFA= 1.25 x NFA (8).

Normalisation to nominal occupancy has been achieved by dividing the internal loads by the number of occupants in the given office area, and is therefore shown in terms of Watts per person.

Calculation of occupancy loads:

The internal load resulting from the occupant persons within the space has been calculated as:

Occupancy Load *(W/m^2 TFA)* = (Number of People x 130 Watts) / Treated Floor Area *(m^2 TFA)*

Where the number of people is that noted from the occupancy recorded during the survey (Table 3), and 130 watts is the total heat emissions of one occupant based on 102 watts sensible and 28 watts latent heat emissions for a seated office worker undertaking moderate work(3). This value is adjusted to account for a mixture of men and women assuming that the number of women is 85% of the number of men. (3)

Calculation of electrical lighting loads:

The internal load resulting from the electrical lighting employed within the space has been calculated as:

Lighting Load *(W/m² TFA)* = (#Fixtures x #Lamps x Lamp Rating *(W)) /* Floor Area *(m² TFA)*

Where: #Fixtures = Number of lighting fixtures with the sample office space

#Lamps = Number of lamps per fixture

Lamp Rating = lamp power rating in Watts *(W)*

Calculation of small power loads:

The internal load resulting from the use of office equipment or so-called small power load is the sum of the loads for each type of equipment. The loads from each type of equipment have been calculated as follows:

Small Power *(W/m²TFA)* = (#Equipment x #Power *(W)* x Nameplate Ratio) / Floor Area *(m²TFA)*

Where: #Equipment = Number of equipment of a particular type

#Power = Power rating in Watts *(W)* for the particular equipment type

Nameplate Ratio = Average power demand *(W)* / Peak rated power demand *(W)*

Both the power demand and nameplate ratio's used for each type of office equipment are standard worst-case values. (3) Table 4 defines the standard power demand and nameplate ratios used for each type of office equipment.

The calculated heat-gains for each site surveyed are summarised in Table 5, in terms of both heat-gains per unit floor area and heat-gains per person for the total and component internal loads.

Equipment Power Ratings & Nameplate Ratios		
Equipment Type	***Worst-case Rated Power Demand***	***Worst-case Name Plate Ratio***
	(Watts)	*(n/a)*
Desktop Computer	187	0.7
Laptop Computer	55	0.7
Printer	150	0.2
Photo Copier	850	0.25
Fax	38	0.25
Desk Fan	60	0.7

** Source: CIBSE Guide A 1999*

Table 4: Standard small power ratings & nameplate

Internal Heat Gains Calculated from Physical Surveys											
Layout information				Occupancy		Lighting		Small Power		Totals	
Site ID	Spatial Layout	Treated Floor Area (m^2 TFA)	Sample Floor Area (m^2)	Thermal Load (W / m^2 TFA)	People Density (m^2 TFA / person)	Lighting Load (W / m^2 TFA)	Lighting Load (W / person)	Total Small Power (W / m^2 TFA)	Total Small Power (W / person)	Space Gains (W / m^2 TFA)	Space Gains (W / Person)
1	M	923	738	8.5	15.4	15.0	230	9.0	139	32.5	499
2	OP	158	126	16.5	7.9	14.6	115	15.9	126	47.1	371
3	LC	70	56	11.1	11.7	18.5	217	16.4	191	46.0	538
4	M	609	487	14.1	9.2	17.6	162	20.3	188	52.0	480
5	OP	175	140	6.0	21.8	9.2	200	**5.7**	**124**	**20.8**	454
6	OP	443	354	16.7	7.8	10.3	80	19.3	150	46.4	360
7	OP	534	427	18.5	7.0	7.6	54	20.4	144	46.6	327
8	LC	130	104	6.0	21.7	7.4	160	10.0	217	23.4	507
9	LC	39	31	13.5	9.6	29.9	**288**	16.4	158	59.8	576
10	OP	**1494**	**1195**	15.5	8.4	8.7	73	17.4	146	41.6	350
11	OP	70	56	7.5	17.4	12.4	216	9.3	163	29.2	509
12	OP	956	765	**5.7**	**22.8**	11.2	256	7.0	160	24.0	545
13	OP	750	600	8.8	14.7	6.8	99	10.0	148	25.6	377
14	CC	155	124	21.8	6.0	8.4	50	23.2	138	53.4	**318**
15	LC	85	68	6.1	21.3	12.2	260	9.5	201	27.8	**591**
16	LC	41	33	9.6	13.6	8.0	108	16.9	**229**	34.4	467
17	OP	563	450	12.7	10.2	13.8	141	13.4	137	39.9	408
18	OP	94	75	9.7	13.5	13.8	185	11.8	159	35.2	474
19	LC	**17**	**13**	23.6	5.5	21.1	116	28.2	155	72.9	401
20	LC	21	17	**30.4**	**4.3**	21.7	93	**34.0**	145	**86.1**	368
21	OP	1180	944	9.7	13.4	8.6	115	11.2	150	29.5	396
22	OP	635	508	17.0	7.7	10.0	76	19.3	147	46.2	354
23	OP	105	84	9.9	13.1	8.7	115	9.9	130	28.6	375
24	OP	68	54	23.1	5.6	**33.9**	191	25.6	144	82.6	465
25	OP	69	56	15.0	8.7	7.5	65	19.2	167	41.7	362
26	OP	65	52	24.1	5.4	8.9	48	29.4	159	62.4	337
27	OP	65	52	24.1	5.4	8.9	48	29.4	159	62.4	337
28	OP	65	52	24.1	5.4	8.9	48	29.4	159	62.4	337
29	OP	70	56	18.7	7.0	**6.2**	**43**	24.4	169	49.3	343
30	OP	105	84	11.1	11.7	12.3	144	13.0	152	36.5	426
Average		***325***	***260***	***14.6***	***11.1***	***12.7***	***133***	***17.5***	***158***	***44.9***	***422***
Standard Deviation		***395***	***316***	***6.7***	***5.5***	***6.7***	***73***	***7.7***	***25***	***17.2***	***81***

**Note: Sites 26, 27, & 28 are standard fit-out with different buildings with a single complex under the same ownership.*

MAX
MIN

Table 5: Internal heat gains calculated from physical surveys

Maximum and minimum values are high lighted, as well as average and standard deviation values shown for each of the calculated values.

OVERVIEW OF RESULTS

Figure 1, shows the calculated total and component heat gains per unit floor area for each site, sorted from highest to lowest total internal gains per unit floor area. The calculated total internal gains as shown in Table 5, averaged 44.9 W/m^2 and ranged from 20.8 to 86.1 W/m^2 of treated floor area..

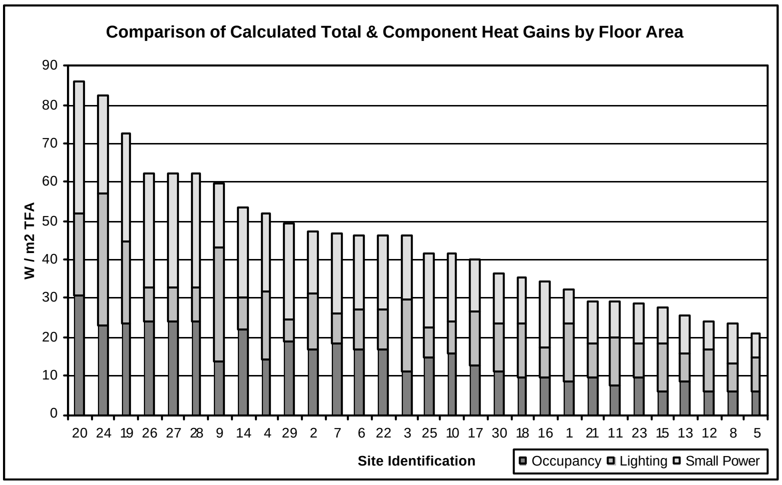

Figure 1: Comparison of calculated heat gains by floor area

When normalised for occupancy levels the calculated total heat gains had an average of 422 watts per person and a range between

318 and 591 watts per person as detailed in Figure 2, which shows the calculated total and component heat gains per person for each site surveyed, sorted from highest to lowest total internal gains per person.

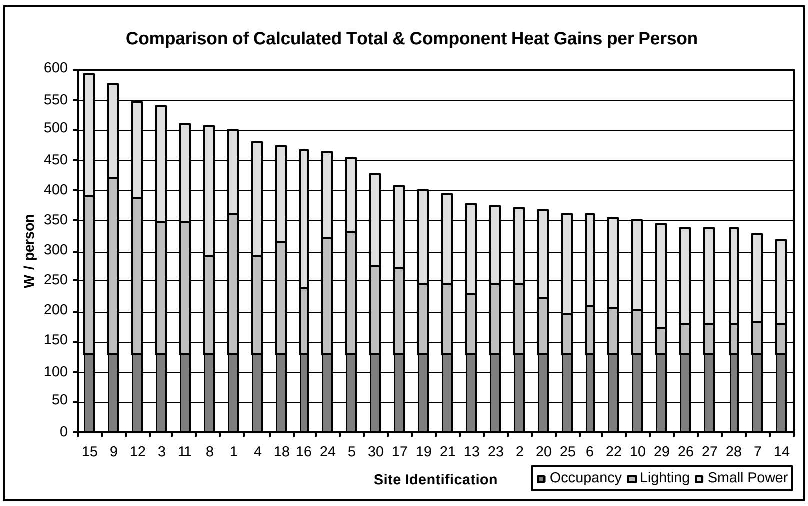

Figure 2: Comparison of calculated heat gains by occupancy

Calculated heat gains resulting from the occupancy in the offices ranged from 5.7 to 30.4 W/m^2 with an average of 14.6 W/m^2 as a result of occupant density varying between 4.3 m^2 and 22.8 m^2 of floor area per person in the offices surveyed.

Lighting heat gains averaged 12.7 W/m^2 and ranged between 6.2 and 33.9 W/m^2 of treated floor area, primarily based upon the type and quantity of light fittings utilised. Lighting heat gains per person averaged 133 watts and ranged from 43 to 288 watts per person, as a function of the type and quantity of lighting fittings used.

Heat gains from small power averaged 17.5 W/m^2, and ranged from 5.7 to 34 W/m^2 of treated floor area and between 124 watts and 229 watts per person. The variation of small power heat gains is a function of both the type and quantity of equipment used as well as the occupant density within the office.

Since all of the component internal loads either directly or indirectly varies as a function of occupant density within the offices, the total internal gains must also vary as a function of occupant density, which has been graphed in Figure 3.

Figure 3 compares the variation of calculated total gains to the occupant density in terms of floor area per person and shows a correlation[1] in which the total internal gains vary as a function of

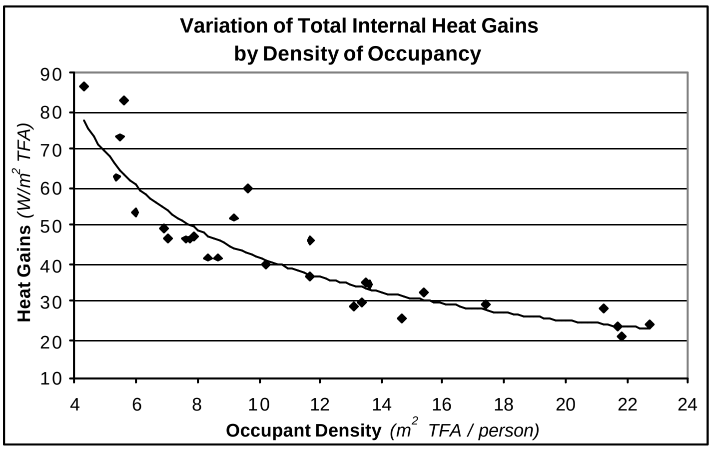

Figure 3: Variation of total internal gains with occupant density

[1] R^2=0.88

the occupant density. This relationship has been determined from the empirical data and is characterised by the equation; $Q_{Int}=224.97D^{-0.7334}$, where Q_{Int} is the total internal heat gains in *W/m² TFA* and D is the occupancy density in *m² TFA per person*. This relationship clearly indicates that the higher the density of occupants (i.e. less the floor area per person), the higher the total internal gains within the office space. Clearly a number of similar lines could be drawn through the data, and more data would help to improve the accuracy of the equation produced. However, the data does show clearly that there is a strong correlation between the occupant density and internal heat gains.

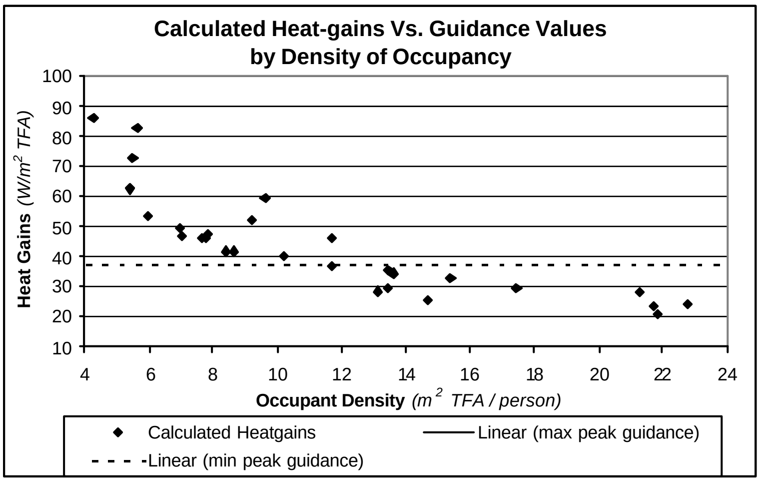

Figure 4: Comparison of calculated internal gains to composite guidance values

When considering any of these values it is important to remember that, as with any 'design' calculation, these are based on 'worst-case' assumptions and therefore represent peak heat gains, implying that actual loads should be lower for the majority of the time.

COMPARISON TO CURRENT STANDARDS AND RULES-OF-THUMB

The currently available design guidance and rules-of-thumb have been summarised and compared to the calculated internal gains from the surveys undertaken in this study, shown in Table 6. Since no single source of design guidance could provide the comprehensive data for this comparison, the design guidance values shown in Table 6 are composite ranges of values derived from a number of sources including; the CIBSE guides(3), Government good practice guides(5), BSRIA rules-of-thumb(4) and a report from an energy monitoring study(9).

The guidance values compare favorably to the calculated values and in particular the maximum calculated heat gains are comparable with the upper end of the guidance range of values. Similarly, the available guidance and rules-of-thumb regarding occupancy levels compares well with the information from the

Ranges of Peak Internal Gains		
Load Type	***Calculated Values W/m2 TFA***	***Composite Guidance W/m2***
	(Min. & Max.)	*(Min. & Max.)*
Occupancy	6 to 30	20
Lighting	6 to 34	8 to 32
Small power	6 to 34	7 to 45
Total internal gains	21 to 86	37 to 90

Table 6: Comparison of calculated internal gains to composite guidance values

30 buildings surveyed in this study. According to the guidance, office occupancy levels are expected to be between $8m^2$ and $16m^2$ of floor space per person$_{(5)}$ in typical offices and down to around $4.5m^2$ per person in 'clerical' offices$_{(4)}$. The actual surveyed occupancy levels ranged between $4.3m^2$ and $22.8m^2$ per person. Furthermore, standard benchmark values for typical and good practice lighting and small power loads from Econ19 for type3 standard air-conditioned offices$_{(8)}$ all fall within the min and max range of the empirical data.

However, as shown in figure 4, the current guidance does not correlate as well when considering the minimum expected peak internal gains. The calculated gains for 12 of the 30 sites, or 40% of the sites surveyed in this study fell below the minimum guidance range.

CONCLUSIONS

The current guidance and rules-of-thumb available to the industry regarding the maximum internal heat gains broadly matches the ranges of calculated occupancy, lighting and small power heat gains based on the surveys undertaken in this study. However, even considering the wide ranges of expected values from the guidance, all the sites surveyed in this study had calculated heat-gains below the maximum predicted by the guidance. Furthermore 40% of the sites had calculated heat-gains below the minimum guidance values indicating that the current guidance would lead to the significant over estimation of heat-gains at least 40% of the time and that the use of the upper limit design guidance from current standards would lead to the overestimation of heat gains in all the Offices studied. Therefore, a more selective method of benchmarking internal heats-gains would be beneficial, a method that more accurately accounts for the minimum peak gains and provides a narrower range of possible values for a given site.

Based upon the results of this study, such a method of benchmarking internal heat-gains could be based on the relationship to occupant density, instead of the traditional benchmarks based on floor area. A similar strategy has been suggested in the good practice guidance$_{(5)}$ relating to small power loads. If the relationship between occupant density and heat gains in the buildings surveyed in this study

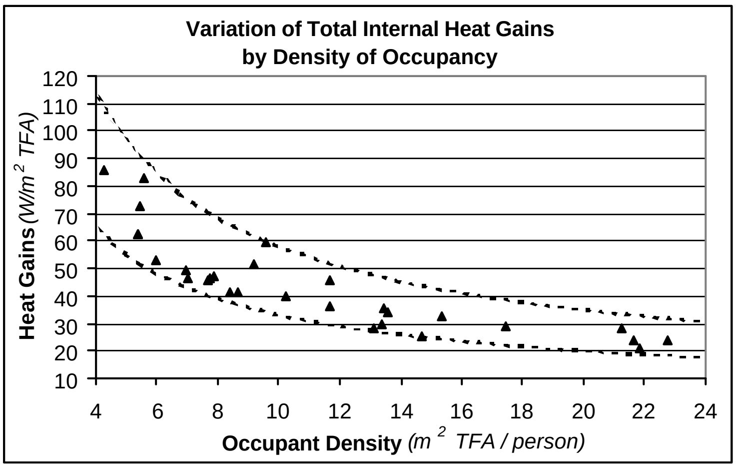

Figure 5: Variation of calculated heat-gains with occupant density, showing min & max range.

holds true for the building stock as a whole, it could be the basis for a more sensible method of benchmarking internal heat gains in UK office buildings.

Figure 5, shows the calculated heat gain values in each of the 30 sites surveyed in this study, as well as indicative maximum and minimum values shown in relation to occupant density. This graph can be used to predict indicative ranges of total peak internal heat gains based upon occupant density.

This method is applicable to all the occupant densities encountered during the surveys unlike the current guidance. Furthermore this method results in a narrower range of predicted values when compared to the current guidance.

Example .

Assuming an occupant density of 10m^2 per person, this method predicts expected total peak internal heat gains of 33 to 56 W/m^2. At an occupant density of 20m^2 per person this method predicts expected total peak internal heat gains of 20 to 35 W/m^2.

At these occupant densities, existing upper and lower internal heat gain guidance limits of 37 and 90 W/m^2 would overestimate the gains by 61% and 157% respectively.

It is only at the higher densities, i.e. <5m^2/person, that the current guidance appears to be accurate – and then it appears that the minimum figure is too low.

Although it is clear that rules-of-thumb should not be used as a substitute for 'full' design calculations in the sizing of building services plant, we acknowledge that rules-of-thumb are often used in the industry, even if only to check that calculated or modelled values are reasonable. The results from this study suggest that the current guidance available to the industry is leading to significant over-estimation of internal heat gains, and a more appropriate benchmarking method such as suggested in this paper would be beneficial to help avoid the oversizing of building services and aid the design of lower energy consuming buildings.

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