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The dark side of occupants' behaviour on building energy use

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ABSTRACT

While most studies focus on energy savings during occupied hours, this paper shows the shocking quantities of energy wasted during non-occupied hours in commercial buildings. At least five detailed energy audits were carried out in the hot and dry climates of Botswana and South Africa. The work shows that more energy is used during non-working hours (56%) than during working hours (44%). This arises largely from occupants' behaviour of leaving lights and equipment on at the end of the day, and partly due to poor zoning and controls. There is a crying need for building occupants to learn to switch off what they do not use. The golden rule is: *"If you don't need it, don't use it!"* This is the simplest and cheapest lesson with amongst the biggest savings. Apart from the above, the work also contributes to several other fields of scientific research: it helps in development of benchmarks from sub-hourly field data; it contributes apportionment of energy amongst sub-systems of HVAC, lighting and office equipment; it provides a picture from cooling dominated climates, which normally differs from the largely researched heating dominated climates; it contributes to development of diversity profiles necessary for improvement of simulation accuracy.

1. Introduction

Energy efficiency and climate change are topical issues the world over. The building sector plays an important role as it accounts for significant percentages of national energy consumption: 23% for Spain [1], 25% for Japan [2], 28% for China [3], 37% for EU [1], 39% for the UK [1], 42% for Brazil [4], over 47% for Botswana [5], 47% for Switzerland [6], etc. It is for this reason that a lot of effort is made to reduce energy consumption in buildings.

Such energy reduction efforts come in widely scattered forms, ranging from use of more energy efficient lighting and equipment, insulation, passive architecture, night-time ventilation, phase change materials (PCM), intelligent controls, smart glazing, adaptive comfort, load shifting, development of legislature and rating procedures, use of renewables, to mention a but a very few.

The above measures are mostly technological as opposed to behavioural. They enjoy massive literature coverage. But since technology is operated by humans, failure of the human component can fail the whole mission. This makes occupancy behaviour as one of the weakest links in the energy efficiency and conservation equation. Existing mass of literature relating to occupant behaviour is a bit skewed towards thermal and adaptive comfort [7–10], as well as mapping out how occupants will react to stimuli like illumination levels, window shading, glare, location of light switch, etc. [11,12]. Work reported in this paper differs slightly from, and is complementary to existing literature: it quantifies the amount of energy wasted during non-occupied hours due to poor occupant behaviour. On the flipside, it defines the untapped energy saving potential from behavioural change.

This waste identified during non-working hours is only a fraction of waste due to poor occupants' behaviour. Literature shows that even during working hours a lot of energy goes to waste due to compromised occupants' behaviour. Lindelöf and Morel [11] have studied light switching patterns of occupants. During working hours, they noticed that due to location of the light switch at the door (out of arm's reach from working desk), lights are left on all day even when they are not needed. This is waste during working hours. Mahdavi et al. [12] tracked 48 offices from three buildings with digital cameras and other data recorders. They noticed that on average, occupants spend more than 50% of the time away from their work station. Lights and office equipment remain operational all day. This is another saving potential on which occupants behaviour has a bearing. On the flipside: if there is so much waste, then there is so much potential!

The work also contributes to energy benchmarking. While some researchers contribute to benchmarking methodologies [13–15], this paper adds figures from field measurements. In addition, most of the internationally used benchmarks were developed in cold countries that are heating dominated. Benchmarks in this paper are from a hot and dry climate where cooling dominates. Hernandez et al. [16] demonstrate that even in European countries

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where benchmarks are fairly developed, issues of performance rating and certification ask for more benchmarks in different building categories (e.g. primary schools, commercial buildings), and such benchmarks are generally scarce.

To the fields of building simulation, the sub-hourly energy consumption profiles presented in this paper may contribute to development of diversity profiles necessary for improvement of simulation accuracy [17].

Behavioural change has energy saving potential comparable, and in most cases, higher than that of technological solutions. The most salient feature of behavioural change is that it is largely no cost, it needs no hi-tech knowledge, it is readily applicable to both new and existing buildings, it is largely appreciated by many (though not practiced), it has a self-perpetuating potential in that once occupants of a building have developed an energy conservation culture, they spread it to their new comers as well as take it with them to other places – the list could be inexhaustible!

In recognition of energy waste in the building sector, the Government of Botswana has pursued a 3-year project (2005–2008), entitled ‘Developing Energy Efficiency and Energy Conservation in the Building Sector, Botswana’ [18], which is funded through Danish International Development Agency (DANIDA) and implemented through the Department of Energy, Ministry of Minerals, Energy and Water Resources, with the assistance of a team of international and local consultants led by Danish Energy Management (DEM). Five out of six of the results published here are from the project. The sixth work (Edenvale) is from a DEM project in Johannesburg.

2. Methodology

State of the art energy auditing equipment was used to perform energy audit on six randomly selected commercial buildings. Sub-hourly electricity consumption data was logged and energy consumption broken down between heating, ventilation and air conditioning (HVAC), plug load (office equipment) and lighting. The consumption was also broken down between working hours (07:30–16:30 h) and non-working hours. Public holidays were classified as wholly non-working hours. For offices that operated from Monday to Friday, their week-end consumption was categorised under non-working hours. For those that operated half-day on Saturday, such was recognised as working hours. Roughly 1 month data-logging was common in most of the buildings, and four months sub-hourly data was available for the University of Botswana campus. For the sixth building in South Africa, sub-hourly data for the whole year was sourced by DEM from a South Africa utility company.

3. Results and discussions

3.1. Sub-hourly profile

Fig. 1 shows the sub-hourly profile for six buildings, five of which are in Botswana and one in the neighbouring South Africa. The figure serves to highlight both the magnitude and pattern of consumption between working and non-working hours.

Fig. 1(a) shows consumption pattern for Botswana Power Corporation (BPC) Customer Service Centre. It is a five storey building served by centralised constant air volume (CAV) system from ground floor upwards. The few rooms in the underground car park have split units. About 70% of the layout is open space, with a few offices for single occupants. The building has significant energy used just before and just after occupancy. Non-occupied measured power density is very high at about 18 W/m^2. This suggests that a lot of equipments are left on after hours. The jagged profile during non-working hours shows that some of the consuming equipments frequently turn on and off, which is characteristic of thermostatic control. This was taken as evidence of air conditioning systems left running after hours. By visiting the building after hours, it was confirmed that some occupants leave their computers on overnight and over the week-end.

Fig. 1(b) shows the profile for the Physics block at the University of Botswana. It is a three storey block with about 70% of the space as large laboratories and the whole of the top floor as single occupant offices. Direct expansion units are used for individual rooms and labs. Air conditioners that are normally set to cooling mode and left on overnight are the reason for electricity consumption after hours. This was picked by several night visits to the building plus interviews. Largely, expensive laboratory equipment were left running throughout the term time even though they were needed only during lab experiment.

Fig. 1(c) shows the profile for the University of Botswana, main campus only. This excludes the Faculty of Engineering, which has separate premises from the main university campus. The daily maximum demand occurs between 09:00 and 13:00 h, with 10:30 and 12:30 h being the most frequent. This is crucial time for demand charge. Gradual reduction of consumption through the night has a similar trend to temperature, which reduces until sunrise. This suggests a link between night-time consumption and weather (temperature), which further suggests that like in the Physics block, a lot of air conditioning systems are left in the cooling mode.

The Ministry of Local Government headquarters (Fig. 1d) is no exception to high non-working hours load density. It is a three storey building with a basement for storage. It s served by a CAV central air conditioning system, timed to starts at 06:00 h and stops at 18:00 h. Some few rooms on the ground floor have split units.

Fig. 1(e) shows the consumption pattern for Air Botswana building. It is a three storey building with highly glazed façade of 40% glazing. Of all the researched buildings, it is the one with more technical than behavioural problems. Indeed computers and lights are left on, but more striking is the chaotic operation of the CAV single zone central air conditioning system: though the building is occupied only 5 days a week, it consumes the same throughout the 7 days of the week. The giant centralised air conditioning is operated 7 days a week instead of 5, in order to serve one small office rented to a car rental company. The problem can easily be remedied by fitting a separate split unit systems to serve such negligible rented space.

The second problem in the Air Botswana building is that the air conditioner starts running at 03:00 a.m. while people occupy the building at 07:30 a.m. Relevant technically responsible people were happy with the 4 h of pre-conditioning time, which is a bad trade-off between morning comfort and energy. While people knock off at 16:30 h, the air conditioning plant switches off at around 22:00 h because that is the time the car rental offices close.

Fig. 1(f) shows the profile for Edenvale Municipal administration building in Johannesburg, South Africa. The figure is a summary of sub-hourly data for the whole year (01-January to 31-December-2006). This is the only case study with data for a full year. It is useful for validating the rest of the case studies that were carried out in roughly 1 month. The building has a peak power density of 38 W/m^2 at around 10:30 h daily and has residual energy of about 15 W/m^2.

3.2. Breakdown of consumption by equipment type

Table 1 shows a break down of consumption by equipment type, as well as the apportionment of energy between official working and non-working hours. The most important part of the table is the last column, which shows how much electricity is used

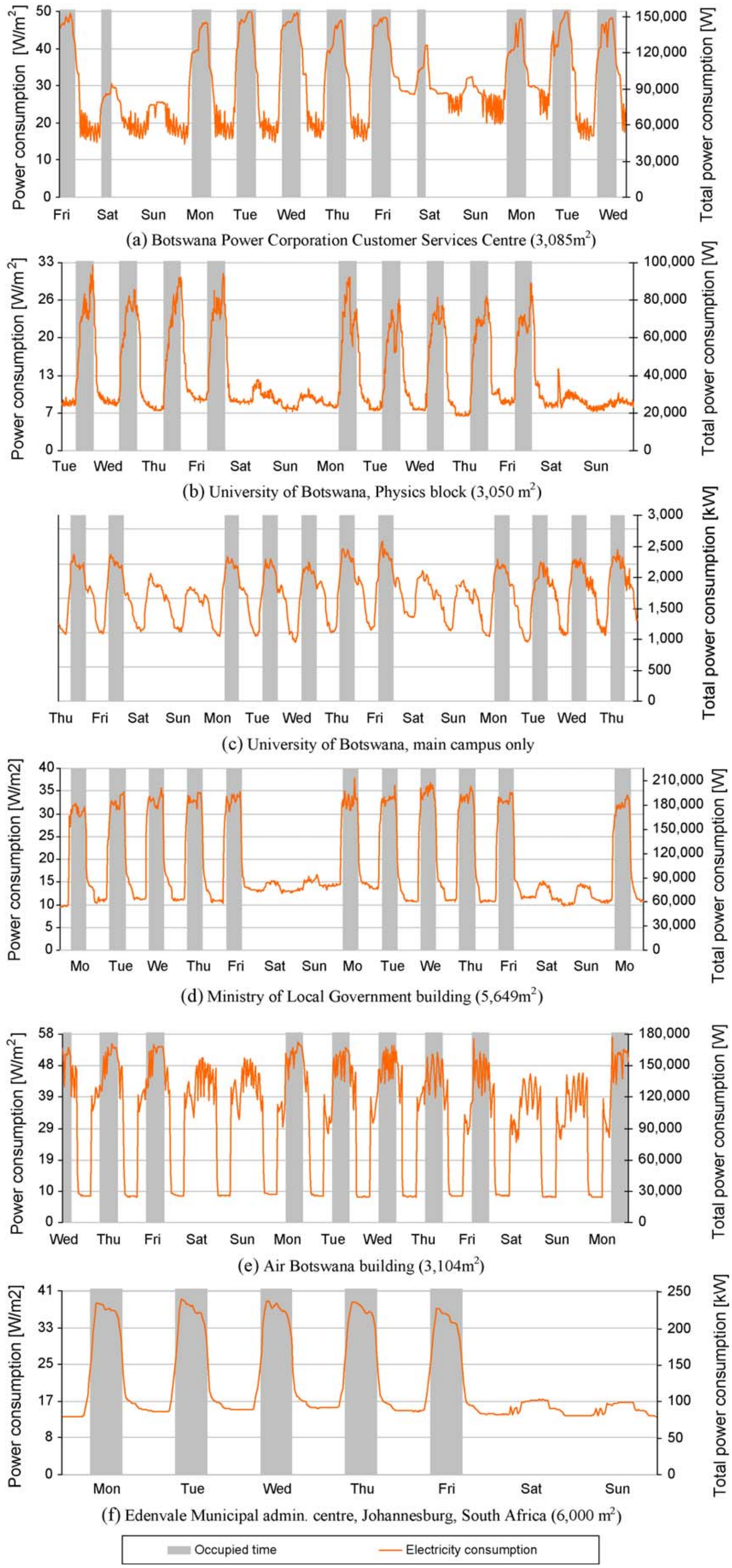

Fig. 1. Sub-hourly power consumption profiles for different buildings audited. (a) Botswana Power Corporation Customer Services Centre (3085 m^2). (b) University of Botswana, Physics block (3050 m^2). (c) University of Botswana, main campus only. (d) Ministry of Local Government building (5649 m^2). (e) Air Botswana building (3104 m^2). (f) Edenvale Municipal admin. centre, Johannesburg, South Africa (6000 m^2).

Table 1
Breakdown of measured energy between official working and non-working hours.

	Installed load density [W/m^2]	Energy utilization index (EUI) [kWh/m^2 year]	% of total energy	% of energy used during week-end	Measured load density during working hours [W/m^2]	Measured load density during non-working hours [W/m^2]	% Energy use during working hours	% Energy use during non-working hours
Univ. of Botswana campus	–	–	–	25%	–	–	35%	65%
BPC Customer Service Centre		162		23%	43	25	37%	63%
HVAC	–	–	–					
Plug load	–	–	–					
Lighting	–	–	–					
Physics block (Univ. of Botswana)		183		23%	19	10	41%	59%
HVAC	113	135	64%					
Plug load	15	40	22%					
Lighting	9	25	14%					
Air Botswana HQ[a]			240	28%	50	26	46%	54%
HVAC	–	246	72%					
Plug load	20	45	19%					
Lighting	9	21	9%					
Min of Local Gov't HQ			92	19%	32	13	51%	49%
HVAC	76	91	78%					
Plug load	18	35	38%					
Lighting	5	11	12%					
Edenvale Municipality, JHB[b], RSA[c]		181		20%	37	15	45%	55%
HVAC	–	–	45%					
Plug load	–	–	27%					
Lighting	–	–	28%					
Average building (excl. University)		172		23%	36	18	44%	56%
HVAC	94	157	72%					
Plug load	18	40	26%					
Lighting	8	19	11%					

[a] HQ – headquarters.
[b] JHB – Johannesburg.
[c] RSA – Republic of South Africa.

during non-working hours. Official working time is between 07:30 and 16:30 h for a majority of the buildings (Air Botswana, Ministry of Local Government, and Physics Block), while for BPC it is 07:30–17:00 h during the week, and 07:30–12:00 h on Saturday. The table shows that on average, more electricity is used during non-working hours (56%) than during working hours (44%). This translates into a huge energy saving potential. If we intuitively expect not more than 20% (still and overestimation) of the electricity to be consumed during non-working hours, that means 36% (56%–20%) can be saved simply by switching off appliances at the end of day. This excludes switching off what is not needed during working hours as exposed by other researchers [11,12]. If this is done, the savings will even be higher. The figures warrant behavioural change as deserving serious commitment from all concerned parties.

An average energy utilization index (EUI) was found at 172 kWh/m^2 year. With this figure, these poor performance buildings are better than typical performance from the South African standard [19] at 255 kWh/m^2 year and UK [20] at 226 kWh/m^2 year. If there is huge saving potential from 172 kWh/m^2 year, there could be similar potential from other countries, especially given that this kind of research seems not to have been done.

Column 5 of Table 1 shows the percentage of energy consumed during the week-end (24 h on both Saturday and Sunday). For BPC building, 5 h was excluded since the building is occupied half-day. The results show that on average 23% of the buildings' energy use go to the unoccupied week-end time. These are significant energy saving potentials.

Columns 6 and 7 show the measured average power intensity (load density) over the audit period. Averages of 36 and 18 W/m^2 were recorded for working and non-working hours, respectively. This means that on average, when people leave buildings, power consumption (in Watts) drops only by half. Nameplate rating from equipments that deserve to run 24 h added up to less than 5 W/m^2 in four of the audited buildings. Such included servers, refrigerators, passage and exterior lighting, UPS, fax machines and specialist equipment. Therefore, 18 W/m^2 when compared to 5 W/m^2 means that there is a 13 W/m^2 saving potential simply by switching off at the end of day. If additional switching off is done during the day on short breaks like lunch; when one goes for a meeting; when there is sufficient daylighting, etc. the 13 W/m^2 saving potential will go higher. This is the power of behavioural change, and it will not be realised if the topic is neglected as is the case in most countries.

4. Conclusions

Energy audits have been performed on six buildings in a hot and dry climate. Five of the buildings are in Botswana and one in neighbouring South Africa. More than 50% of energy is used during non-working hours than during official working hours of 07:30–16:30 h. This is consistently found in the audited buildings and it could be the tip of the iceberg for a national (Botswana) or international perspective. The biggest consumers have been shown to be air conditioning systems, followed by equipment that are left ON unnecessarily at the end of day (mostly computers), then lighting. Even though the world seems to be highly focused on improving technology for energy efficiency, waste of energy from poor occupants' behaviour seems to warrant more serious attention. The paybacks could be very high due to both the high levels of waste, and due large numbers of participants around the world since it is a no-cost measure that everybody knows of and appreciates (though not practiced). Many have practised it at home. Unlike most technological solutions that are mostly economic to the few new buildings, behavioural change can be applied as well to the large existing stock of buildings. The habits developed in office buildings can positively affect practices in other sectors like residential.

Energy awareness campaigns are a worthwhile investment. There is probably a limitless number of resources that can be put together to bring out the best of occupancy behaviour. These could range from energy awareness campaigns, incentives, punitive measures, technological, etc.

For energy benchmarking, an average figure of 172 kWh/m^2 year was found for five buildings. In comparison with international published figures, this looks like fair performance. Put this against the fact that more than 50% of it is unnecessary waste, it makes one wonder whether the 'Good practice' figures put up internationally have similar levels of waste entrained in them!?

19–28% (average 23%) of the buildings' energy went to the unoccupied part of the week-end. This is amongst the easiest target since one appropriate action lasts a couple of days.

Reviewed literature has shown that even during working hours, there are sign of wasted energy. This raises a question: of all the energy used in buildings, how much of it is waste? In other words, what is the 'operational efficiency' of today's buildings?

On diversity profiles, the paper has published average sub-hourly energy consumption of six buildings in a hot climate. The profile and relative magnitude of both the occupied and non-occupied times may be informative to simulation experts in developing input profiles necessary for simulation accuracy.

References

[1] L. Perez-Lombard, J. Ortiz, C. Pout, A review on buildings energy consumption information, Energy Buildings 40 (2008) 394–398.
[2] G. Yoon, et al., Study on the energy conservation performance of air-conditioned system for the building combined a double skin and earth-to-air heat exchanger, in: The 2005 World Sustainable Building Conf. in Tokyo, September, 2005, No. 01-102.
[3] J.C. Lam, C.L. Tsang, L. Yang, Impact of lighting density on heating and cooling loads in different climates in China, Energy Conversion and Management 47 (2006) 1942–1953.
[4] S. Delbin, V. Gomes da Silva, Energy efficiency simulation of buildings in Brazil: proposal of methodology for insertion in design practice, in: The 2005 World Sustainable Building Conf. in Tokyo, September, 2005, No. 01-135.
[5] Central Statistics Office, Energy Statistics, Government of Botswana Publication, 2002.
[6] M. Zimmermann, H.J. Althaus, A. Haas, Benchmarks for sustainable construction—a contribution to develop a standard, Energy and Buildings 37 (2005) 1147–1157.
[7] J.F. Nicol, M.A. Humphreys, Thermal comfort as part of a self-regulating system, Building Research and Practice (Journal of CIB) 6 (3) (1973) 191–197.
[8] J.F. Nicol, M.A. Humphreys, Adaptive thermal comfort and sustainable thermal standards for buildings, Energy and Buildings 34 (2002) 563–572.
[9] H.B. Rijal, P. Tuohy, M.A. Humphreys, J.F. Nicol, A. Samuel, J.A. Clarke, Using results from field surveys to predict the effect of open windows on thermal comfort and energy in buildings, Energy and Buildings 39 (2007) 823–836.
[10] P.O. Fanger, J. Toftum, Extension of PMV model to non-air conditioned buildings in warm climates, Energy and Buildings 34 (2002) 533–536.
[11] D. Lindelöf, N. Morel, A field investigation of the intermediate light switching by users, Energy and Buildings 38 (2006) 790–801.
[12] A. Mahdavi, A. Mohammadi, E. Kabir, L. Lambeva, Occupants' operation of lighting and shading systems in office buildings, Journal of Building Performance Simulation 1 (1) (2008) 57–65.
[13] T. Olofsson, A. Meier, R. Lamberts, Rating the energy performance of buildings, The International Journal of Low Energy and Sustainable Buildings 3 (2004).
[14] W.L. Lee, H. Chen, Benchmarking Hong Kong and China energy codes for residential buildings, Energy and Buildings 40 (2008) 1628–1636.
[15] K.W. Mui, L.T. Wong, L.Y. Law, An energy benchmarking model for ventilation systems of air-conditioned offices in subtropical climates, Applied Energy 84 (2007) 89–94.
[16] P. Hernandez, K. Burke, J.O. Lewis, Development of energy benchmarks and building energy ratings for non-domestic buildings: an example for Irish primary schools, Energy and Buildings 40 (2008) 249–254.
[17] D. Bourgeois, C. Reinhart, I. Macdonald, Adding advanced behavioural models in whole building energy simulation: a study on the total energy impact of manual and automated lighting control, Energy and Buildings 38 (2006) 814–823.
[18] http://www.EECOB.com.
[19] CSIR Building and Construction Technology, International building energy standards (codes); their relevance for the proposed SA national energy efficiency standard SANS 0204, Ref. BOU/C 399, 2004.
[20] UK Department of the Environment, Transport and the Regions (DETR), Energy Consumption Guide 19: Energy Use in Offices, DETR, London, 2003.