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Uncertainties in Non-Domestic Energy Performance Certificate Generating in the UK

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Abstract: In light of the recent launch of the Minimum Energy Efficiency Standard targeting the energy performance of commercial buildings, this study compares the energy performance certificates of three UK hotels generated by two different software, EDSL TAS and SBEM, both accredited by the UK government for the purpose. Upon finding the results discrepant, the study finds that the two software's different assumptions for the air permeability rate contribute to the discrepancy. While modifying this value makes the results from the two software more aligned, further issues regarding the validation process arise. The study continues to find that the underlying issue can be found within the National Calculation Methodology's assumption about domestic hot water consumption in hotels. These assumptions are compulsory to follow when generating a non-domestic energy performance certificate in the UK, therefore, any uncertainties within them can affect all the buildings seeking an energy performance certificate within that sector. Finally, the study discusses that, for meeting the carbon dioxide mitigation goals, it is necessary to make changes to the current procedure of energy performance certificate generating in the UK to increase its reliability.

Keywords: minimum energy efficiency standard; MEES; energy performance certificate; EPC; non-domestic; hotels; validation; compliance modeling

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1. Introduction

1.1. Overview

With the growing concern among public and scientific bodies regarding the potential impacts of climate change, the UK government, alongside other European countries, has aimed for the ambitious goal of 80% reductions in greenhouse gas (GHG) emissions by 2050, compared to 1990s levels [1]. It is believed that one of the most effective means of reducing the GHG emissions is energy efficiency [2], which can be pursued in different sectors. However, the high share of the building sector in overall energy consumption and energy-related GHG emissions [3,4] signals the significant potentials for emission reductions within this sector [5]. In line with other steps taken to fulfill the requirement of this goal, the UK government has recently put forward a new legislation called Minimum Energy Efficiency Standard (MEES). It asks the owners of commercial buildings to ensure a minimum energy performance certificate (EPC) rating of E or above for their property, before renting out or selling their property [6].

EPCs are energy labeling tools and were first introduced in the Energy Performance of Building Directive (EPBD), which came into effect in 2002 and was revised in 2010. Among many European countries, EPC is known as the source of information about how energy-efficient a building is [7]. Despite similarities [8], European countries have different approaches to EPC generation [9–11]. In the UK, the process of generating an EPC involves collecting information about both the building fabric and building services such as heating, cooling, and hot water systems. These data are then submitted to government-approved software. The choice of the software depends on whether the building is domestic or non-domestic. For the latter, the process should also include the standard profiles determined by the National Calculation Methodology (NCM). These profiles dictate some of the input data such as heating and cooling set points, occupancy hours, people density, lighting level, and domestic hot water (DHW) consumption rate for different zones in a non-domestic building. Following these standard assumptions—specific to the type of non-domestic building—is mandatory when carrying out the non-domestic EPC analysis in the UK.

Apart from being actively used in policy-making in the UK [8], the EPCs are recognized as tools for comparing the energy performance of buildings of similar types, and essentially, they are expected to provide information about the potential heating, cooling, and lighting bills of a building [12]. However, despite the initial expectations that energy efficiency labels would help in reducing the carbon dioxide (CO_2) emissions without compromising occupants' comfort [13], emerging evidence from different studies suggests that they may not always reflect how energy-efficient a particular building is, and uncertainties within the generating procedure can result in considerable overestimation or underestimation of energy consumption. Some of these studies are discussed in Section 1.2.

1.2. Existing Literature

To generate an EPC, an independent energy assessor evaluates the property and uses a software/algorithm to conduct a thermal analysis of the building based on a set of input data. Tronchin and Fabbri [14] stated that the evaluation and subjective judgment of the assessor affects the EPC rating, causing an impact on the property's financial value. Similar to the previous study but without the mention of financial impact, Jenkins, Simpson and Peacock [15] carried out a study in which multiple assessors evaluated the same property and produced EPC ratings with considerable differences. Based on this, the study suggested that the recommendations for energy efficiency improvement through EPC assessments might not yield the expected energy savings. The risk of ineffectiveness of a retrofitting measure caused by an unreliable EPC was also raised by Tigchelaar, Daniels and Menkveld [9].

Apart from assessors' judgment and evaluation, other factors can contribute to EPC uncertainties. Osso et al. [16] stated that uncertainty and lack of robust information about input data can be a massive contributor. In their opinion, unless the information and data are entered with certainty, an increase in the number of input data does not necessarily result in a more accurate EPC. An example is the 2012 revision of the French EPC where the number of input data doubled compared to an earlier version, resulting in more uncertainty in the generating process [16]. Contrary to this study, some other researchers believe that simplified models—as opposed to those requiring much more input for running full thermal analyses—are to blame for EPC inaccuracies [17].

From an energy policy point of view, default values, average and normative assumptions for EPC generation helps in comparability of EPCs. However, for the sake of research purposes, this might lead to inaccuracy in results [18]. One of the very few studies on non-domestic EPCs in the UK found that having to follow specific guidelines and default values for cooling set points in a hotel results in underestimation of cooling energy consumption [19]. Irrespective of the cause, the uncertainties of EPCs might hinder their application as an energy comparison tool [20]. This matter has also been raised by other studies. Backhaus, Tigchelaar and de Best-Waldhober [21] suggested that applicability of the EPC depends on its quality.

One of the aspects related to EPC uncertainties is overestimation of energy consumption, which has been discussed in some studies: Balaras et al. [22] investigated the comparability of 8500 EPCs against the corresponding dwellings' measured energy consumption and found that, on average, the EPCs overestimated the energy consumption by 44%. Laurent et al. [18] found that despite some differences in the generating process, EPCs in the UK, Germany, France, and Netherlands all overestimated the heating energy consumptions. The study also found that the risk of overestimating the energy consumption increases with the age of the building. Majcen, Itard and Visscher [23] carried out a large-scale study on 200,000 domestic EPCs in the Netherlands and found that for dwellings with a low-energy label, i.e., inefficient buildings, the overestimation of energy consumption was much higher. On the other hand, the study demonstrated that buildings labeled as energy-efficient happened to have higher energy consumption than what was predicted by the EPC. A study on cases from Switzerland's domestic sector found that buildings with poor energy efficiency ratings sustain a higher risk of energy overestimation, up to 37% [24]. In another study on 537 high-performance dwellings, the researchers found that the Flemish Energy Performance framework for domestic buildings overestimated the gas consumption for space heating and hot water and underestimated the electricity use for purposes such as lighting [25]. With regards to the impact of uncertainties, Hjortling et al. [26] claimed that as the EPCs in Sweden are based on the measured energy consumption—rather than theoretical calculations—Swedish EPCs can be deemed reliable.

As shown in the summary above, there is a body of literature questioning the consistency and reliability of EPCs. However, most of these studies are focused on domestic EPCs and housing stock. Therefore, a gap in the literature regarding the non-domestic EPCs seems noticeable. This paucity of information can be partly due to the fact that until recently, commercial buildings' contribution to energy consumption was much less than that of domestic buildings [27,28]. Also, the majority of energy efficiency policies in Europe were focusing merely on domestic buildings [18]. However, with the expected growth in the commercial service sector [29] and the full focus of MEES requirements on commercial buildings, it is time to investigate the reliability of non-domestic EPCs.

By looking at the EPCs generated by two accredited software packages—for three different UK hotels—this paper aims to shed some light on the issue of reliability of non-domestic EPCs in the UK. This study was designed and carried out when discrepancies of one band or more were observed between the EPC ratings from two accredited software packages for the same buildings. By consulting the scholarly literature, the authors found evidence—elaborated in the preceding paragraphs—of the possibility of receiving different EPC ratings for the same building when the evaluations are conducted by different assessors and/or through different software tools. The authors decided to investigate the potential cause(s) of this discrepancy, for which they went through all the steps of EPC generation in each of the two software packages. Upon finding the contributing factor, a new question emerged about how close the simulation results were to the measured data for each building. To answer this question, the authors carried out further analyses and an issue with the mandatory guidelines of NCM was found, which could affect all the buildings within this sector. The following sections elaborate on the whole process. To avoid repetition, whenever the word EPC is mentioned in the following sections, it is referring to the non-domestic EPC.

2. Materials and Methods

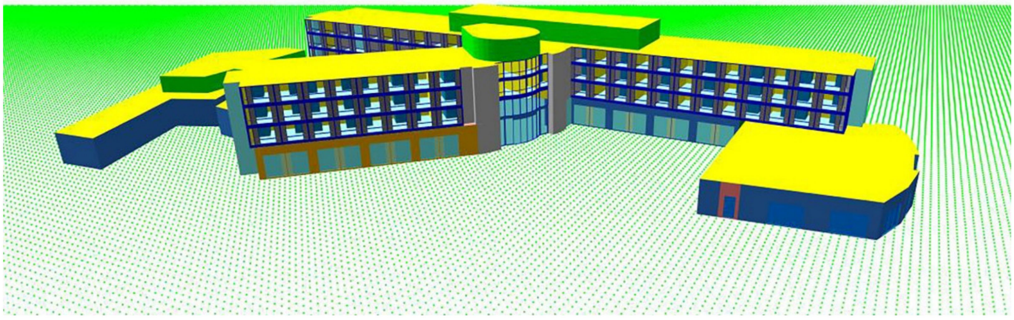
This study starts by comparing the EPCs generated by two different software packages for three existing hotels. Both SBEM (Building Research Establishment, Watford, UK) and EDSL TAS (Environmental Design Solutions, Milton Keynes, UK) are approved and accredited by the UK government for generating EPCs. SBEM is the UK Government's Simplified Building Energy Model, widely used by commercial assessors for non-domestic EPCs, and TAS is one of the three government-approved Dynamic Simulation Models for the same purpose [30]. As required, both programs follow the guidelines from NCM and use similar input data, Table 1. Both programs apply whole building thermal analysis and go through several steps prior to EPC calculations. The main difference between the two programs is their approach toward thermal simulation: SBEM applies steady-state simulation, using monthly average weather conditions [31], while TAS carries a dynamic simulation. This means that TAS traces the thermal state of the building through a series of hourly snapshots during which the impact from different thermal processes occurring in the building is calculated. The heat transfer mechanisms considered in TAS include the following:

- Conduction in the building fabric,
- Convection at building surfaces and external convection due to wind speed,
- Long-wave radiation exchange between surfaces, the sky, and the ground,
- Solar radiation affecting each building element,
- Gains from occupants, equipment, and lighting,
- Heat transfer caused by the air movement between different zones [32].

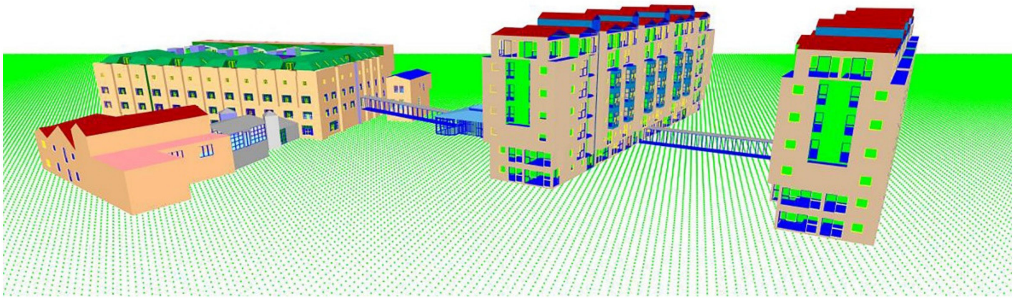
Through this, TAS is capable of providing hourly predictions of energy consumption while SBEM only provides the overall, i.e., annual predictions. The modeling and simulation process in TAS is usually more time consuming. Further information about EDSL TAS can be found in the works of Amoako-Attah and B-Jahromi [33] and Rotimi et al. [34], while information on SBEM is fully provided in the documents by Department for Communities and Local Government [12,31]. Full details on how the EPC bands are calculated are provided in [35] while a summary of the process is provided in [19]. For each of these three buildings the SBEM assessment had been done by independent assessors prior to the start of this study, while TAS analyses for the buildings were carried out by the authors of this paper, therefore, this paper reports on the results of TAS simulations while SBEM results are only used for comparison purposes. Figure 1 and Table 2 provide information about these three hotels.

Table 1. Summary of input data needed for calculations.

Input Data	Source for SBEM [36].	Source for TAS
Building Geometry	Assessor reads from drawings or direct measurements.	Assessor models the building in 3D Modeler module of the software based on direct measurements or from drawings.
Weather Data	Internal database.	Internal database or CIBSE TRY/DSY weather files.
Activities Assigned To Each Zone	Selecting from internal database based on the site visit or according to the documents.	Zones are introduced by the assessor based on the site visit or according to the documents.
Occupancy Profiles For Activity Areas	For consistency purposes, assessor selects the NCM standard profiles for the building type and activity.	For consistency purposes, assessor selects the NCM standard profiles for the building type and activity.
Building Fabric Specification/Construction	Assessor selects from an internal Construction and Glazing database or defines their user-defined construction.	Assessor selects from NCM Construction database or define their user-defined construction.
HVAC Systems	Assessor selects from internal database or inputs data directly.	Assessor selects from internal database in UK Building Regulation 2013 Studio.
Lighting	Assessor selects from internal database or inputs data directly.	Assessor selects from internal database or inputs data directly.



(**a**)



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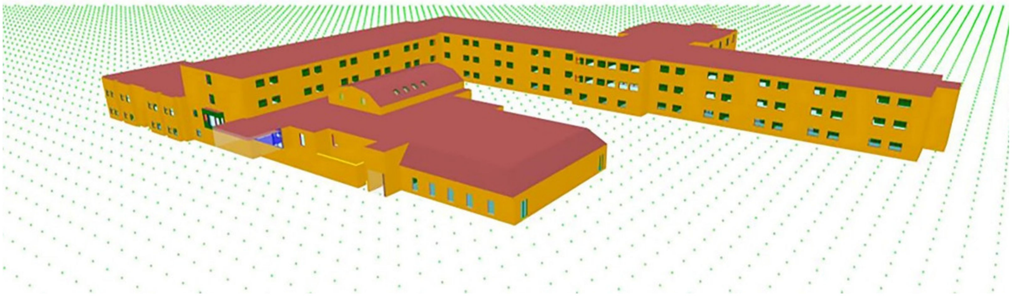

(**c**)

Figure 1. Geometries of the hotels: (**a**) Hilton Reading; (**b**) DT Docklands; (**c**) Hilton Watford.

These three cases are examples of the existing UK hotel building stock. Each of these hotels reflects some aspects commonly found within this stock. The hotels have different envelope types (sealed/non-sealed), different materials and years of construction, their heating, cooling and hot water is provided through different systems, and their level of access to services (e.g., comfort cooling in guest rooms) is varied.

Furthermore, the three cases in this study represent the existing stock in terms of the building purpose:

- Hilton Reading is an example of newly constructed (2009) purpose-built hotels,
- Hilton Watford is an example of older constructions, a purpose-built hotel from the 1970s,
- DT Docklands is an example of historical buildings converted for the purpose.

Like other energy simulation software, TAS needs weather data. Test Reference Year (TRY) and Design Summer Year (DSY) weather files are compatible with TAS. TRY files are used for predicting average energy consumption and compliance with the UK building regulation, while DSY files are suitable for overheating analyses [37]. For all the three cases of this study, London TRY was used as it was the closest weather file to the location of the buildings among the 14 sites currently available from the Chartered Institution of Building Services Engineers (CIBSE), responsible for providing the weather files for the UK building regulation compliance assessments [37].

Table 2. Specifications of the cases studied in this paper.

Hotels	Location	Year of Construction	Floor Area (m^2)	Heating System/ Cooling Systems	DHW
Hilton Reading	Reading	2009	12,300	Fan coil units served by air handling units and chillers	Gas-fired boilers
Dt Docklands	London	Two buildings from 19th century and the rest from 1980s.	18,122	- Fan coil units served by air handling units and chillers - VRF systems - Splits and multi splits units	Electrical heaters and gas-fired boilers
Hilton Watford	Watford	1970s	~10,000	- Electrical, and central radiators/natural ventilation for most of the guest rooms - Split and multi splits for public area and a few of guest rooms	Gas-fired boilers

As demonstrated in Table 3, for each building, the EPC by TAS shows smaller numeric values. This difference in numeric values resulted in different EPC bands, especially when the values were close to the borderline scores.

Table 3. Energy Performance Certificate (EPC) bands and numeric values for the hotels by the two software.

Hotel	EPC by SBEM (by Independent Assessors)	EPC by TAS (by the Authors of This Paper)
Hilton Reading	C(57)	B(50)
Dt Docklands	E(111)	C(74)
Hilton Watford	C(59)	B(48)

With findings from the literature on the possibility of receiving large differences in the EPC results from different assessors and/or different tools—discussed in Section 1.2—the authors decided to investigate the reliability of the simulation results. As mentioned earlier, SBEM assessments were carried by independent commercial assessors and not the authors of this work; therefore, the reliability assessment was focused on TAS simulation results. In order to decide on the reliability of the energy simulation models, the common practice is to validate the simulation results against the buildings' measured energy consumption. While there is currently no guideline on validating the approach for EPC assessments in the UK, the study used two statistical indicators for comparing the energy consumption predicted by TAS with the measured energy consumption data of the hotels. These indicators were normalized mean bias error (MBE) and coefficient of variation of the root mean square error (Cv(RMSE)). While the first one shows how close the predicted values are to the measured data, the latter accounts for cancellation error, i.e., impact of positive and negative errors, Equations (1) and (2).

$$\text{MBE}_{(\%)} = \sum_{i=1}^{Np}(Si - Mi) / \sum_{i=1}^{Np}(Mi) \tag{1}$$

$$\text{Cv(RMSE)}_{(\%)} = \frac{\sqrt{\sum_{i=1}^{Np}(Si - Mi)2/Np}}{Mav} \tag{2}$$

where Si and Mi are predicted and measured data points, respectively. Np is the number of data points at interval p, i.e., $N_{monthly} = 12$. Mav is the average of measured data.

The results of the validation process—elaborated in the next section—suggested that TAS simulations could be validated against the measured data. In the next step toward finding the reason behind the conflicting results of the two software tools, the modeling and simulation steps of each of them were checked. This step led to finding an input factor that the two software tools used with markedly different values. In SBEM this input parameter was entered by the assessor depending on the building age, while in TAS it was a default value. Upon finding this contributing factor, new rounds of simulations for all the three buildings were carried out in TAS with the updated factor and the results were again compared with the SBEM scores and the practice of validation was carried out once more. The outcome of this second round of simulation encouraged a further look into the current EPC generating procedure, which is discussed fully in the next section.

3. Results

3.1. Validation of TAS Results

As discussed in Section 2, statistical indicators of MBE and Cv(RMSE) were used to validate the TAS results against the measured data. Table 4 shows the results of the validation process for TAS simulation according to these indices.

Table 4. Validation indicators for TAS simulation results.

	Hilton Reading	**DT Docklands**	**Hilton Watford**
MBE	−8.2%	13.9%	3.8%
Cv(RMSE)	15.9%	15.9%	15.8%

The US Department of Energy [38] suggested that in the presence of the microclimate for the exact location of the building, the acceptable ranges for monthly values of MBE and Cv(RMSE) should be ±5% and 15%, respectively. This may not be applicable to many simulations as the weather files are usually not available for every location, not to mention the normalized nature of many weather files currently available. It is also important to mention that EPC simulation is a compliance modeling. This means that while the model is a precise replication of the actual building in many aspects such as building size and fabric, orientation, and internal thermal zones, it is also necessary to follow NCM's specific guidelines imposing fixed occupancy profiles, standard DHW consumption profiles, and standard heating and cooling set points. This may result in an increased gap between the simulation results and measured data. Regarding all of the above and according to some studies where higher values of MBE were considered acceptable—up to ±15%—[39,40] the TAS simulations were accepted as a close prediction of the measured data. The higher level of overestimation in the DT Dockland model, i.e., +13.9%, is attributable to the fact that in this hotel, two out of four main buildings were built in the mid-19th century with solid brick walls—common in pre-1919 constructions. There is evidence from literature that the U-values of solid walls are significantly lower than the standard values considered in guidelines and standard assessments [41,42], resulting in an overestimation of the energy consumption.

3.2. The Factor Contributing to the Two Software Programs' Discrepant Results

By validating the results of TAS simulations and assuming the validity of SBEM analyses done by independent assessors, the reason behind the discrepancies between the EPC ratings of these software tools was sought in their process of modeling. After going through all the steps of modeling, the reason behind the discrepancy was found to be the two programs' very different choices of air permeability rate (APR). Air permeability is an indicator of how airtight a building is, and APR is defined as "air leakage rate per hour per square meter of envelope area at the test reference pressure differential of 50 Pascals" [43] (p. 28). By default, TAS considers this value as 5 $m^3/m^2.h$ @ 50 Pa while SBEM links it to the year of construction, i.e., for buildings built before 1995 the value is 25 and for buildings after 1995 the value is 10 m^3/m^2.h @ 50. The value 5 is too optimistic and only achievable for a highly airtight building complying with UK Building Regulation 2013 [44]. Having found the source of discrepancies, new rounds of simulation were carried out in TAS with updated values for APRs. The updated EPC ratings by TAS are shown in Table 5. As demonstrated, by manually changing the APRs in TAS and carrying out the simulations, the new EPCs were closer to those from SBEM, previously demonstrated in Table 3.

Table 5. TAS Simulation results with updated air permeability rates (APR).

Hotel	Year of Construction	TAS Default APR	Initial EPC by TAS	Updated APR	Updated EPC by TAS
Hilton Reading	2009	5	B(50)	10	C(51)
DT Docklands	Varied construction dates but all before 1995	5	C(74)	25	D(82)
Hilton Watford	1970s	5	B(47)	25	C(53)

As shown in Table 5, despite the changes in APRs, in the case of DT Docklands, the gap was still one band. This can be attributed to the possibility of SBEM assessors considering the construction year of the oldest two buildings, i.e., 19th century for the other two buildings in the complex while in TAS each building in DT Docklands complex was modeled and simulated according to its actual year of construction.

The increase in the APR means a higher ventilation rate, hence increased heat loss in the building, resulting in more energy consumption in the heating-dominant time of the year, Figure 2. This is consistent with the literature [45]. The validation procedure was also carried out for the new round of simulations, Table 6. As shown, the overestimation of energy consumption for the two cases of DT Docklands and Hilton Watford increased in the new round of simulation.

Table 6. Validation indicators for simulation results with updated APRs.

	Hilton Reading	DT Docklands	Hilton Watford
MBE	−6.3%	25.5%	12.02%
Cv(RMSE)	14.1%	28.5%	19.08%

3.3. The Potential Reason behind the Increased Gap between the Predicted and Measured Energy Consumption

As mentioned, the updated APRs were more realistic, as it would be very difficult—if not impossible—to achieve an APR as low as 5. However, as Table 6 shows, this realistic assumption increased the gap between the predicted and measured energy consumption in two out of three cases. If a more realistic assumption increased the overestimation of the overall energy consumption, then this might be a signal of overestimation in one/some of the energy end uses. Also, as the models were checked closely and every effort was made to accurately replicate the actual buildings, the contributing factor should be related to the assumptions/guidelines that are beyond the control and decision of the assessor—the authors', in this case.

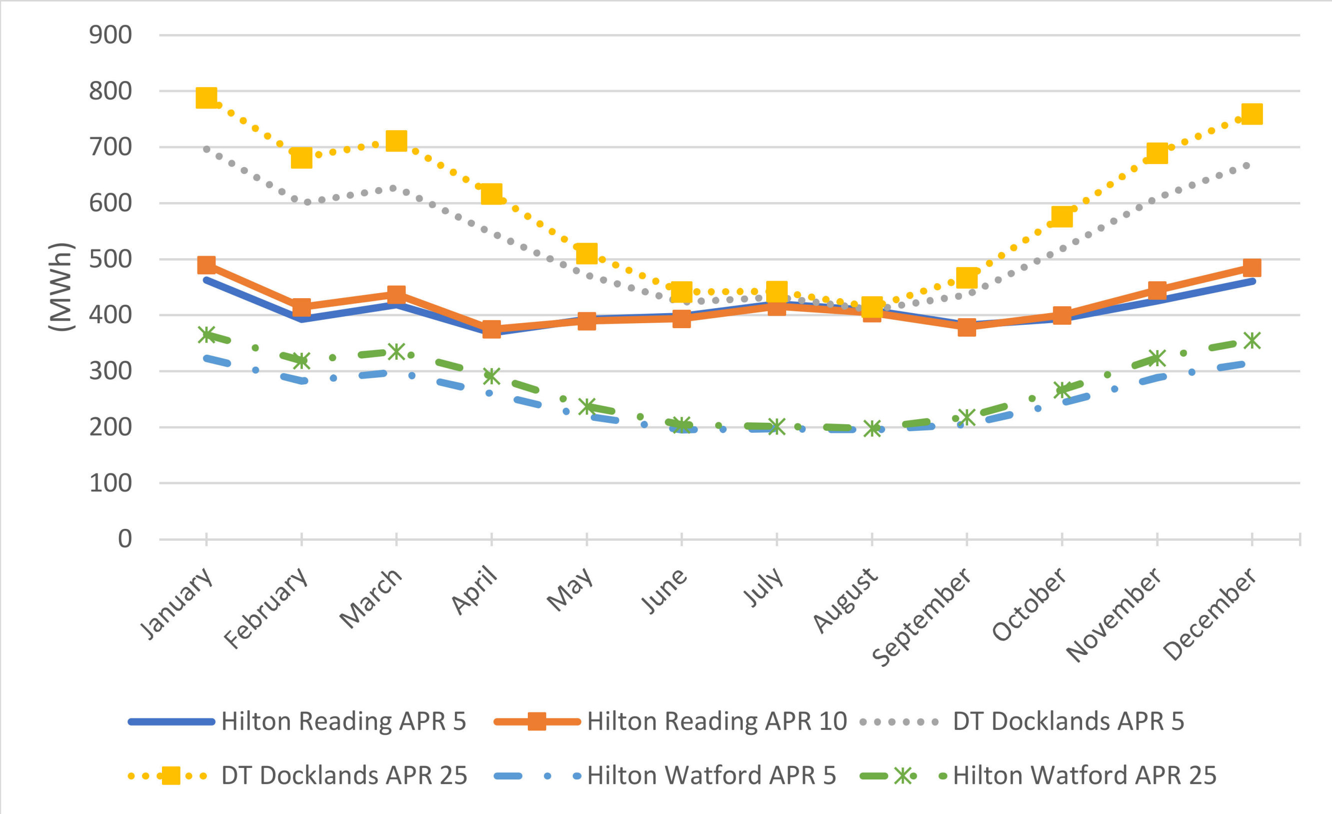

Figure 2. Monthly predicted energy consumption with initial and updated APRs.

To further investigate this issue, the buildings' end use energy consumption as predicted by TAS were studied, Figure 3. The breakdown of simulated energy consumption for each building in Figure 3 was based on the EPC calculation, using the standard assumptions of NCM, meaning that the share of DHW, heating, equipment, auxiliary, lighting, and cooling energy consumption for each hotel was calculated according to NCM standard profiles for hotels. As demonstrated in Figure 3, for all the three buildings, around half of the predicted energy consumption belonged to the DHW end use, despite having hot water systems with a minimum efficiency of 91%. Heating energy consumption for Hilton Reading—a sealed and relatively new building—was 12% and for DT Docklands and Hilton Watford—leaky buildings with high APR—the percentages were 39% and 33%, respectively. Although the literature recognizes the heating (especially in colder climates) and DHW as two major end uses in the hotel sector, a share of 45–55% for DHW seemed too high. Some of the values found in the literature for the share of DHW in total energy consumption follow as below: 12–36% for hotels in Balearic Islands [46], less than 25% for an average hotel in the UK [47], 18% for hotels in Greece [48], and 17% for a typical hotel in the EU [49].

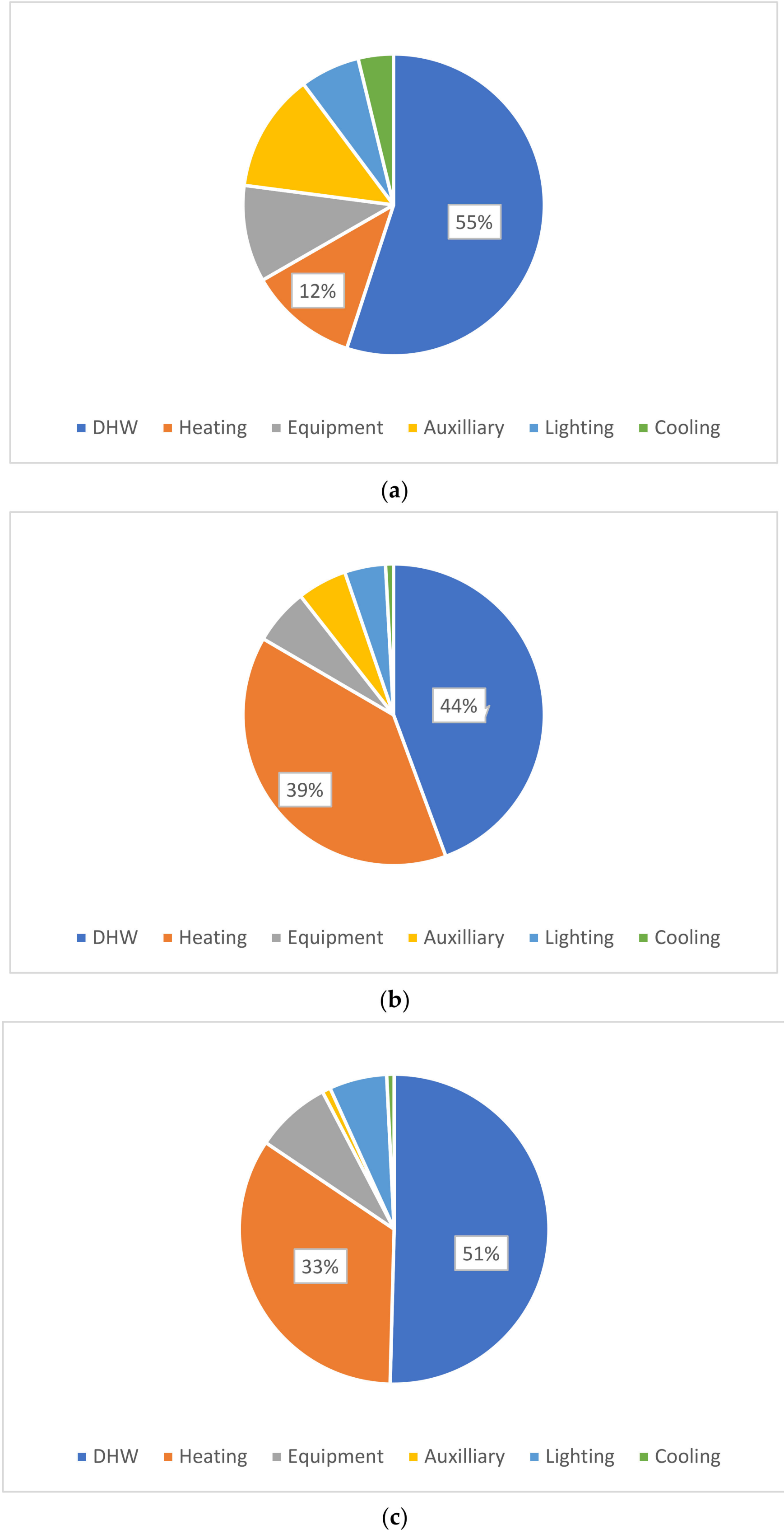

Figure 3. Annual energy consumption breakdown with updated APRs: (**a**) Hilton Reading; (**b**) DT Docklands; (**c**) Hilton Watford.

3.4. Evidence on the Potential Overestimation of DHW

According to NCM profiles for hotels, the DHW demand for each zone in a hotel is expressed in liter per day per square meter of area. As an example, the amount of DHW needed for an ensuite guest room is 13.12 L/d/m^2. In order to decide whether NCM's guideline for DHW in hotels is an overestimated assumption, measured and predicted hot water consumption were compared for these hotels. Table 7 shows the predicted hot water consumption in guest rooms with NCM's assumption of 13.12 L/d/m^2 over the course of one calendar year (365 days). Guest rooms were chosen for this comparison as most of the hot water consumption in hotels are in guest rooms, and they cover a significant share of each hotel's area.

Table 7. Predicted hot water consumption with NCM assumptions for guest rooms.

Hotel	Area Covered by Guest Rooms (m^2)	NCM Assumption for DHW (L/d/m^2)	Predicted DHW (l) Consumption for Guest Rooms
Hilton Reading	5480.2	13.12	26,243,581.76
DT Docklands	9591.53	13.12	45,931,918.864
Hilton Watford	4760.07	13.12	22,795,023.216

Table 8 shows the total water—cold and hot—consumption in liters for the hotels during 2016–2018. By assuming a 50% share for hot water [50], the annual hot water consumption was acquired.

Table 8. Measured data for water consumption during 2016–2018.

Hotel	Year	Measured Water Consumption (l)	Hot Water (l) (50% of Total)
Hilton Reading	2016	13,460,974.58	6,730,487.29
	2017	13,019,275.41	6,509,637.71
	2018	13,701,974.12	6,850,987.06
DT Docklands	2016	38,408,927.46	19,204,463.73
	2017	31,395,940.70	15,697,970.35
	2018	38,084,928.07	19,042,464.03
Hilton Watford	2016	20,113,962	10,056,981
	2017	16,448,968.93	8,224,484.47
	2018	18,139,103.38	8,812,483.36

Comparing the numbers in the last columns in Tables 7 and 8 shows the high differences between the predicted and measured hot water consumption, denoting an overestimation of hot water consumption by NCM guidelines. Full details on these Tables and further calculations with considerations of monthly occupancy rates are provided in the Appendix A, Tables A1–A3.

This overestimation can also be demonstrated in terms of energy consumption. As always, it is best to compare the predicted and the measured data. However, separate measurement of energy consumption for different end uses is not a common practice in the commercial sector, if at all possible. The monthly measurement of gas and electricity was available for these three hotels. Therefore, the gas consumption during the hottest time of the year—when there is potentially no heating required—was chosen as a base for comparison. Figure 4 shows the measured gas consumption for Hilton Watford during 2016–2018. Hilton Watford was chosen as all the DHW for this hotel is provided by gas-fired boilers, unlike the DT Docklands, where gas-boilers and electric heaters are jointly used for the purpose. The DHW in Hilton Reading is also provided by gas-fired boilers but having high levels of food preparations in this hotel hindered the focus on gas consumption for DHW. As shown, for all three years, the lowest amount of gas consumption was measured during July, for which the numbers are shown in Table 9.

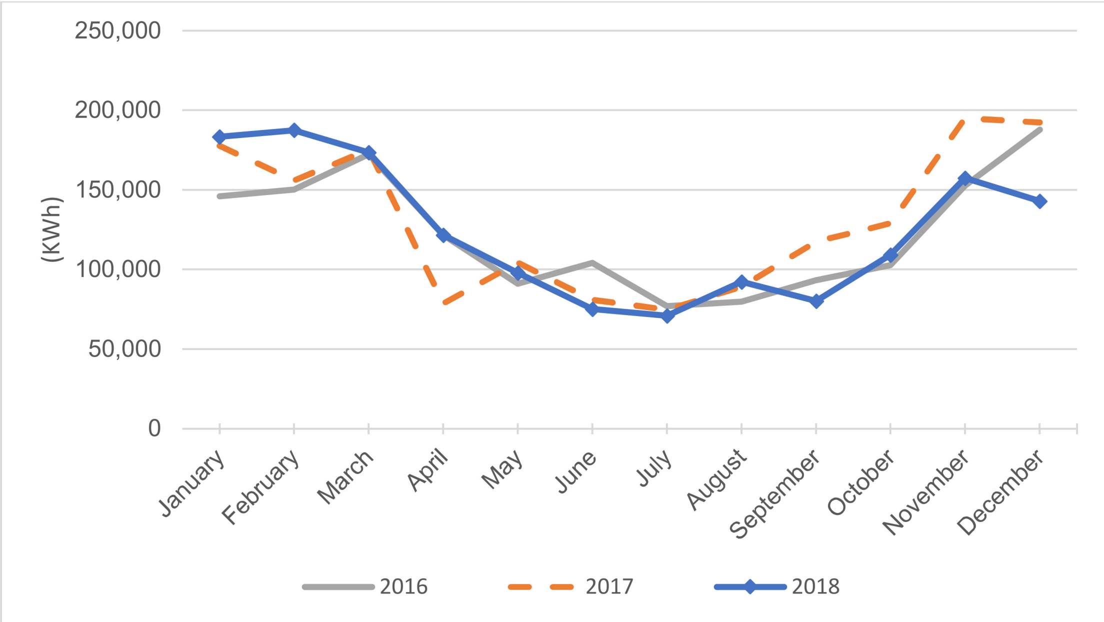

Figure 4. Monthly measured gas consumption for Hilton Watford during 2016–2018.

Table 9. Hilton Watford's gas consumption and occupancy rate for July during 2016–2018.

	Gas Consumption (kWh)	Occupancy Rate (%)
2016	77,043.62	87.08
2017	74,772.80	83.89
2018	70,960.03	89.73

As it is very unlikely to have any heating demand during July, it is safe to assume that almost all the gas consumption during July was for water heating purposes, except for a small amount for kitchen cookers. This was while the DHW energy consumption predicted by NCM guidelines for July for this hotel amounted to around 142,000 kWh. Although NCM profiles tend to consider the worst-case scenarios—here 100% occupancy—given the fact that the measured data in Table 9 are also for high levels of occupancy rates, it is clear that the NCM assumptions for DHW were an obvious overestimation. As mentioned already, there was a significant paucity of information about non-domestic EPCs, making it difficult to compare the finding of this study—i.e., the overestimation of DHW by NCM guidelines—with cases from other countries. In the context of domestic EPCs, overestimation was mostly reported for heating end use [18,23,25].

4. Discussion

The results and findings of this study can be discussed from several different points. One point is the issue of reliability of EPC results. Through the process explained in Section 3, this study found a potential source of overestimation. As this overestimation was caused by the NCM standard profiles, the impact can extend beyond the cases of the current study; it can adversely affect any building seeking an EPC rating within the hotel sector in the UK. While some level of uncertainty within the assumptions of this kind might be inevitable [51], significant overestimation or underestimation of energy consumption by EPC can affect its reliability; therefore, these uncertainties should be addressed and avoided. While considerable underestimation of the actual energy consumption can result in failing to meet the expected GHG emission reductions on a national level [19], significant overestimation of energy consumption can risk the effectiveness of retrofitting measures [9,15]. As an example, the high share of DHW energy consumption caused by following the NCM profiles can mislead the efforts aimed at improving the EPC and reducing the annual CO_2 emissions. If the efficiency of boilers/electric heaters are increased, this may improve the EPC rating due to the significant share of DHW in annual energy consumption, but in reality the amount of reduction in CO_2 can be much less as the real share of DHW in the measured energy consumption of the hotel is much less than the predicted amount.

In line with the previous point, the next issue to be discussed is the lack of validation guidelines specific to the EPC calculations. As discussed in the main text, although there are already statistical indicators for validation of performance modeling, there are no guidelines on how to validate an EPC assessment. One can argue that EPCs are essentially tools for policy makers to compare the energy efficiency of similar buildings, attaining an overall view of the levels of energy efficiency in the building sector, without necessarily the need for validation against the measured consumption. While this can be partially true from a policy point of view, the high levels of discrepancies reported in different studies [9,17,18,22,51,52] show that at least from a research point of view this issue should not be overlooked. Furthermore, with the MEES requirement in action and the possibility of receiving different EPC ratings through different tools and/or assessors, if a building receives markedly different EPC ratings through different assessors/tools, there should be means of validation to decide which rating is a more accurate reflection of the building's energy performance.

As mentioned, the risk of receiving different EPC ratings for the same buildings has been widely discussed in the context of domestic EPCs. In this study, the same issue was spotted in the context of non-domestic EPCs. After finding the factor contributing to this discrepancy and addressing it, this study further proceeded to find a potential source of uncertainty within the current procedure of non-domestic EPC generation in the UK. This source of uncertainty is the NCM's overestimation of DHW. Through the process taken here and its results, this study hopes to have made a small contribution to the field of non-domestic EPCs.

Future works can investigate whether there are further issues with the assumptions currently used in the UK's EPC scheme and investigate the impact of these potential uncertainties through sensitivity analysis. Meanwhile, the findings of this study can be used to signal that as the NCM guidelines are applied on all the commercial buildings eligible for an EPC, the impact from any major inaccuracy within them could lead to widespread unreliability of EPCs in the sector. It is important to bear in mind that despite the good intentions and concepts behind the MEES requirement, the current procedure in generating EPCs needs further improvement and modification. This is necessary before it can truly contribute to reducing the CO_2 emission in the non-domestic building sector. Steps should be taken to improve the reliability of the EPC scheme for both the policy makers' and the clients' benefit. This will be beneficial to both policy makers and clients: avoiding significant underestimation of energy consumption can help to achieve the expected long-term goals in GHG emissions reductions, while avoiding significant overestimation of energy consumption can reduce the risk of non-compliance with MEES requirements and the subsequent penalties.

5. Conclusions

This study was carried out to investigate the comparability of EPCs generated by two different software packages—SBEM and TAS—for three existing hotels. Using the current available validation steps, it was demonstrated that the estimated data from TAS for the two hotels with higher levels of discrepancies—DT Docklands and Hilton Watford—were closer to the measured data. Subsequently, it was found that the default air permeability rate of 5 used by TAS was not realistic. Further simulations with the higher yet more realistic air permeability rates resulted in EPCs from the two software programs becoming more consistent, followed by higher levels of overestimation for two cases. After a breakdown of the energy end uses and comparison with the data available from the literature and measured data, a potential overestimation of DHW loads by NCM standard profiles was signaled. In order to find evidence on this potential overestimation, measured and predicted data for water consumption of the three hotels and also the gas consumption of one of them were compared. The result of these comparisons supported the idea of DHW overestimation in NCM assumptions.

The study continued to discuss that improved reliability and certainty of EPCs are needed for both meeting the expected goals of GHG mitigation policies and compliance with MEES requirements.

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Appendix A

The information provided in Tables 7 and 8 of the main text is presented in the below Tables with more detail.

Table A1. Data for measured and predicted water consumption in Hilton Reading.

Hilton Reading	**2016**		**2017**		**2018**		**Predicted DHW Consumption for the Guest Rooms Based on NCM Assumption of 13.12 L/d/m^2 for 100% Occupancy Rate**	**Average Occupancy Rate (%) during 2016–2018**	**Predicted DHW Consumption for the Guest Rooms Based on NCM Assumption of 13.12 L/d/m^2 for Average Occupancy Rate**
	Water Consumption (l)	**Occupancy Rate (%)**	**Water Consumption (l)**	**Occupancy Rate (%)**	**Water Consumption (l)**	**Occupancy Rate (%)**			
Jan	760,998.56	64.76	1,018,998.08	69.69	983,998.14	70.28	2,228,906.94	66.82	1,489,361.78
Feb	1,483,997.20	75.09	956,998.19	74.57	1,022,998.07	69.60	2,013,206.27	74.21	1,494,076.42
Mar	635,998.80	72.38	996,998.12	74.85	993,998.12	81.98	2,228,906.94	73.61	1,640,808.76
Apr	1,146,997.83	75.78	1,047,998.02	73.16	1,042,998.03	74.40	2,157,006.72	75.51	1,628,711.26
May	1,047,998.02	76.79	1,015,998.08	80.41	985,998.14	78.45	2,228,906.94	77.21	1,720,926.16
Jun	1,707,996.77	88.24	1,163,997.80	83.54	1,032,998.05	84.52	2,157,006.72	84.63	1,825,580.93
Jul	723,998.63	87.17	1,290,724.83	83.47	1,612,996.95	82.13	2,228,906.94	85.05	1,895,769.24
Aug	1,276,997.59	88.96	1,193,970.47	81.71	1,303,997.54	74.42	2,228,906.94	83.04	1,850,803.07
Sep	1,317,997.51	85.84	1,114,197.90	80.02	1,148,997.83	77.59	2,157,006.72	80.08	1,727,431.41
Oct	1,382,997.39	80.83	1,112,097.90	79.08	1,186,997.76	73.61	2,228,906.94	80.63	1,797,163.22
Nov	1,230,997.67	77.79	1,222,297.69	78.78	1,174,997.78	72.98	2,157,006.72	75.39	1,626,200.46
Dec	743,998.59	68.94	884,998.33	67.37	1,210,997.71	66.01	2,228,906.94	68.86	1,534,898.59
Total	13,460,974.58		13,019,275.41		13,701,974.12		26,243,581.76		20,231,731.31
Share of the hot water	6,730,487.29		6,509,637.71		6,850,987.06				

Guest room area for Hilton Reading: 5480.2 m^2.

Table A2. Data for measured and predicted water consumption in DT Docklands.

DT Docklands	2016		2017		2018		Predicted DHW Consumption for the Guest Rooms Based on NCM Assumption of 13.12 L/d/m^2 for 100% Occupancy Rate	Average Occupancy Rate (%) during 2016–2018	Predicted DHW Consumption for the Guest Rooms Based on NCM Assumption of 13.12 L/d/m^2 for Average Occupancy Rate
	Water Consumption (l)	Occupancy Rate (%)	Water Consumption (l)	Occupancy Rate (%)	Water Consumption (l)	Occupancy Rate (%)			
Jan	4,328,991.82	58.39	1,852,996.50	63.65	2,357,995.55	56.75	3,901,064.23	59.59	2,324,836.31
Feb	3,974,992.49	71.26	2,204,995.84	73.33	2,737,994.83	75.43	3,523,541.89	73.34	2,584,132.76
Mar	3,890,992.65	61.97	2,281,995.69	74.71	3,339,993.69	77.37	3,901,064.23	71.35	2,783,478.24
Apr	2,521,995.24	73.02	2,930,994.46	73.64	2,583,995.12	78.34	3,775,223.45	75.00	2,831,417.59
May	4,046,992.36	75.22	2,727,994.85	79.78	3,048,994.24	81.79	3,901,064.23	78.93	3,079,104.21
Jun	3,874,992.68	77.41	4,087,992.28	81.00	3,521,993.35	90.44	3,775,223.45	82.95	3,131,482.38
Jul	2,932,994.46	84.58	1,904,996.40	83.88	7,446,985.93	91.06	3,901,064.23	86.51	3,374,619.20
Aug	2,932,994.46	74.48	2,493,995.29	71.36	2,879,994.56	87.82	3,901,064.23	77.89	3,038,488.93
Sep	2,800,994.71	85.29	2,397,995.47	79.25	2,537,995.21	88.47	3,775,223.45	84.34	3,183,860.56
Oct	2,365,995.53	77.52	2,843,994.63	79.78	2,819,994.67	89.36	3,901,064.23	82.22	3,207,497.32
Nov	2,366,995.53	86.50	2,551,995.18	79.33	2,722,994.86	86.18	3,775,223.45	84.00	3,171,320.87
Dec	2,369,995.52	72.24	3,115,994.11	69.45	2,085,996.06	69.73	3,901,064.23	70.47	2,749,188.30
Total	38,408,927.46		31,395,940.70		38,084,928.07		45,931,885.34		35,459,426.66
Share of the hot water	19,204,463.73		15,697,970.35		19,042,464.03				

Guest room area for DT Docklands: 9591.523 m^2.

Table A3. Data for measured and predicted water consumption in Hilton Watford.

Hilton Watford	2016		2017		2018		Predicted DHW Consumption for the Guest Rooms Based on NCM Assumption of 13.12 L/d/m^2 for 100% Occupancy Rate	Average Occupancy Rate (%) during 2016–2018	Predicted DHW Consumption for the Guest Rooms Based on NCM Assumption of 13.12 L/d/m^2 for Average Occupancy Rate
	Water Consumption (l)	Occupancy Rate (%)	Water Consumption (l)	Occupancy Rate (%)	Water Consumption (l)	Occupancy Rate (%)			
Jan	1,781,996.63	70.71	1,234,997.67	75.55	1,193,997.74	71.73	1,936,016.484	72.66	1,406,734.56
Feb	2,050,996.13	78.09	1,287,997.57	79.50	1,276,997.59	77.59	1,748,660.05	78.39	1,370,806.63
Mar	2,658,994.98	77.08	1,755,996.68	74.94	1,505,997.16	74.02	1,936,016.484	75.34	1,458,673.92
Apr	1,523,997.12	80.43	909,998.28	70.25	1,420,997.32	74.45	1,873,564.339	75.04	1,406,005.95
May	1,510,997.15	79.44	1,391,997.37	83.06	1,345,997.46	81.21	1,936,016.484	81.24	1,572,753.18
Jun	1,746,996.70	83.22	1,400,997.35	78.17	1,372,997.41	78.87	1,873,564.339	80.08	1,500,412.77
Jul	1,507,997.15	89.73	1,387,997.38	83.89	1,801,996.60	87.08	1,936,016.484	86.90	1,682,356.69
Aug	1,659,996.86	86.68	1,578,997.02	84.55	1,968,996.28	90.65	1,936,016.484	87.29	1,689,955.03
Sep	1,539,997.09	83.57	1,344,997.46	79.73	1,391,997.37	84.98	1,873,564.339	82.76	1,550,582.66
Oct	1,274,997.59	82.81	1,337,997.47	76.11	1,391,997.37	87.19	1,936,016.484	82.04	1,588,262.13
Nov	1,360,997.43	82.13	1,539,997.09	76.95	1,628,996.92	82.43	1,873,564.339	80.51	1,508,323.38
Dec	1,495,997.17	73.77	1,276,997.59	69.76	1,323,997.50	74.06	1,936,016.484	72.53	1,404,236.47
Total	20,113,962.00		16,448,968.93		17,624,966.72		22,795,032.79		18,139,103.38
Share of the hot water	10,056,981.00		8,224,484.47		8,812,483.36				

Guest room area for Hilton Watford: 4760.072 m^2.

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