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*Article*

# A Band Rating System for Domestic Water Use: Influences of Supply and Demand Options

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**Abstract:** The national demand for water in the UK is predicted to increase, exacerbated by a growing UK population, and home-grown demands for energy and food. When set against the context of overstretched existing supply sources vulnerable to droughts, particularly in the SE of the UK, the delicate balance of matching minimal demands with resource secure supplies becomes critical. Whilst demands can be decreased through changes in user behaviour and adoption of technological efficiency and supplies can be supplemented with additional local sources (e.g. rainwater harvesting – RWH and greywater – GW), careful consideration of future water use performance, particularly in increasingly dense city centres needs to be considered. For this purpose indicators and benchmarks are particularly useful, although any system, once adopted, must be robust and fully understood in terms of its sensitivity to future changes.

This paper presents a new band rating system for measuring the water using performance of domestic dwellings and considers the impact(s) when making changes to 'internal' demands either through technological efficiency or user behaviour alone. The sensitivity of water performance is tested further when combining these changes with additional localised supplies (i.e. RWH and GW) and 'external' gardening demands. This includes the impacts (in isolation and combination) of the following: occupancy rates (1 to 4); roof size (12.5 m$^2$ to 100m$^2$); garden size (25 m$^2$ to 100m$^2$) and geographical location (NW, Midlands, SE) with yearly temporal effects (i.e. rainfall and temperature). Lessons learnt from analysis of the proposed band rating system are made throughout this paper, in particular its compatibility with the existing Code for Sustainable Homes (CSH) accreditation system. Conclusions are subsequently drawn for the robustness of the proposed system.

**Keywords:** urban water demand management, user behaviour, water saving devices

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## 1. Introduction

A benchmark measures performance using indicators. Benchmarks set a target and thereby allow us to move from where we are now to where we want to be (in terms of water-use performance) and indicators, of which there are many, allow for measurement of progress along the way (Walton et al 2005, Hunt et al, 2008, 2009). In terms of domestic water benchmarking an appropriate indicator would show how much water is consumed within a specified time period. Typically for domestic properties two water-use indicators are adopted; one specifies how many litres are consumed per person per year (l/person/yr) while the other specifies litres required per square metre of property per year (l/m$^2$/yr). The benchmarks set currently in Code for Sustainable Homes (CSH, see CLG, 2010), the UK's premier benchmarking system for water, sets the following performance levels:

- <80 l/person/day for Levels 5 and 6 (the best performing benchmarks);
- <105 l/person/day for levels 3 and 4 (mid-range benchmark);
- <125 l/person/day for levels 1 and 2 (lowest performing benchmarks).

These are appropriate levels for urban city living and the use of a 'per person' measure instead of a 'per m$^2$' measure is appropriate given the human element of water use – after all an empty city property does not of its own consume water (unless leaks ensue). Hunt et al. (2013) suggests that the amount of resources consumed within the home is most strongly influenced by the technologies that are adopted (i.e. technological efficiency) and how they are used (i.e. user behaviour) and this includes water (see Zadeh et al., 2013a). Therefore a better understanding of these influences with respect to benchmarking is required. If we pose two questions this highlights very quickly the thinking behind this paper and the shortfall of existing benchmarking systems like CSH; Q1. Which of (A) to (D) below uses least water? Q2. Which one is accredited under the benchmarking system 'code for sustainable homes'?

A. 8 minutes in a highly water efficient shower;
B. 4 minutes in a standard shower;
C. 2 minutes in a power shower;
D. 30 minutes in a quarter filled 230 l bath.

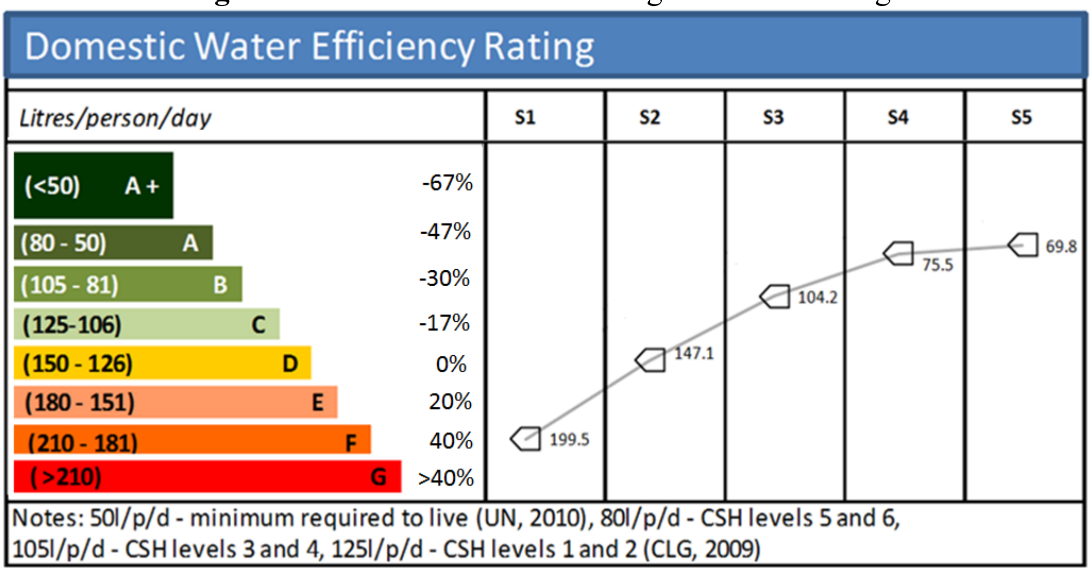
The answer is they all use the same volume of water, however, only A receives accreditation in CSH. Benchmarking and accreditation (CSH awards a range of credits) in the UK appears to be about adopted technologies as opposed to water use per se. This paper questions whether this goes far enough and whether it subsequently provides a robust platform for future city water considerations.

This paper presents a new banding system for measuring the water using performance of domestic dwellings and considers the impact(s) therein when making changes to 'internal' demands, either through technological efficiency or user behaviour alone (Section 2). The sensitivity of water performance is then tested further when combining these changes with additional localised non-potable supplies (Section 3), i.e. GW (Section 3.1) and RWH (Section 3.1 and 3.2) and 'external' gardening demands (Section 3.3). Therein the impacts (in isolation and combination) of the following are considered: occupancy rates (1 to 4); roof size (12.5 $m^2$ to 100$m^2$); garden size (25 $m^2$ to 100$m^2$); rainfall (and temperature) according to geographical location (NW, Midlands, SE) this includes yearly temporal impacts specific to these locations (i.e. rainfall and temperature). Lessons learnt from analysis of the proposed banding system are made throughout this paper, in particular its compatibility with the existing code for sustainable homes accreditation system. Conclusions are subsequently drawn for the robustness of the proposed system.

### *1.1. Proposed band rating system*

The proposed banding system presented in Figure 1 is not dissimilar in its approach to that used for energy performance certification of buildings. The band ratings relate to the total daily volume of mains water consumed per person. The band ratings range from A+ (i.e. best performance, up to 67% reduction compared to band D - average UK demand) to G (i.e. worst performance, >40% increase compared to band D). The band ratings and associated performance levels are aligned directly with levels adopted within CSH, ensuring full compatibility with an accreditation system now widely recognised and accepted by builders and end-users within the UK (CLG, 2009). The best performing CSH levels (i.e. 5 and 6) require only 80 litres daily consumption per person – this is represented by band A in the proposed band rating system.

**Figure 1.** The influence of technologies on band ratings



For reference throughout all levels of demand accredited by CSH are shown in the notes at the bottom of band rating figures. Band 'A' (47 to 67% reduction compared to band D) and band A+ pushes the bounds of what could be achieved far beyond CSH levels. Band A+ (<50 litres/person/day) is wholly appropriate as it is equivalent to the minimum level required to live, as specified by the UN (UN, 2003). S1 to S5 represent different design cases that have achieved a specified level of performance (in terms of litres of water consumed per person per day). S2 is assumed to be equivalent to the current average water consumption levels in the UK (147 litres/person/day) and represents a baseline against which all other design cases are compared. S1 represents a 33% increase in demands compared to this design case whereas S3 to S5 represent decreases from 30% to 53% respectively. Sections 2.1 and 2.2 show how these design cases can be achieved through changes to technological efficiency or user behaviour respectively.

## 2. Influence of demand-side options on band rating

In this section it is shown how the water-using performance and band-rating of a conventional domestic property can be influenced significantly by user technologies (Section 2.1) and user behaviour (Section 2.2).

### *2.1 User technologies*

The demands shown in Figure 1 can be achieved through gradual changes in the efficiency of user technologies (Table 1). It can be seen that S1 is achieved merely by changing the shower to a power shower with a flow rate of double that adopted in S2. The reduced water demands and improved band rating achieved in S3 assume a lower flush toilet, lower flow shower, smaller bath and more water efficient washing machine and dishwasher. The water use assigned to sinks (as assumed within the CSH methodology) unchanged (10.4 l/person/day) in all design cases. It is a small % of total use (<10%) but still an area where improvements could be made – or where demands may be significantly higher than the static value assumed in CSH. [N.B. The flow rate of taps (typically 4 l/min) is important and could be used rather than a static value. However, no values for user behaviour are given in CSH currently. Dividing 10.4 by 4 gives 2.6 minutes and this could be assumed as the base case against which changes are made. Accordingly a 1 minute change in use would result in either 4 litres being used or saved.] The colour coding in Table 1 identifies where the changes in demand have been made and is directly aligned with the benchmarks (and related % changes) identified in Figure 1. For example the orange 'D' band rating shows no change from average UK technological efficiency in S2, whereas the red 'G' band rating in S1 highlights an increase in demand of >40% compared to S2 (in this case due to a shower with double the flow rate). This increase in demand, and associated band levels D to G, are not present in CSH and are a valuable addition - demands can go up, as well as down. S5 achieves the lowest demand through adoption of appliances that are more water efficient and the removal of bath(s) and dishwasher(s). The lower you can go in terms of technological efficiency within each design case might, in some case, influence functionality (i.e. the ability of achieving what technology is designed to do) and comfort levels (i.e. the ability of the technology to deliver a 'user experience' that is acceptable). When considered together with costs these have a strong influence on *'acceptability'* or what might be termed *'liveability'* options. For example can a 6 litre/min flow rate shower deliver the same shower experience as a 24 litre/min power shower? If not then acceptability and widespread adoption will be inhibited. What is the limit, or has it been reached? If so could a (re)design deliver the same user-experience and function (i.e. personal washing). Might improvements to aeration technologies help?

### *2.2. User behaviour*

In order to find the influence of technological efficiency alone the levels of user behaviour adopted in cases S1 to S5 (Table 1) were assumed constant and operated at the level of S2 (Table 2). Whilst this might be considered a shortfall, as the human element is strongly influential in water demands within the home and can be highly variable - even within a single household (Spehr and Curnow, 2007), this is the same methodological approach applied in CSH.

Notwithstanding this shortfall, Table 2 shows that the same levels of water-use performance outlined in Table 1 can be achieved through changes to user behaviour alone with no changes to technological efficiency. Improved water-using performance in this way is not currently rewarded in CSH.

**Table 1:** Technologies (italics show % change from design case S2)

| End Use | Units (L – Litres) | Design Case | | | | |
|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S5 |
| WC [a,b] | l/flush | 6 *(0)* | 6 *(0)* | 4.5 *(-25)* | 2.6 *(-57)* | 2.6 *(-57)* |
| Shower [a,b] | l/minute | 24 *(+100)* | 12 *(0)* | 8 *(-33)* | 6 *(-50)* | 6 *(-50)* |
| Bath [a,b] | L | 230 *(0)* | 230 *(0)* | 116*(-50)* | 97 *(-58)* | None *(-100)* |
| Dishwasher [b] | l/setting | 1 *(0)* | 1 *(0)* | 0.67 *(-33)* | 0.67 *(-33)* | None *(-100)* |
| Washing machine [b] | l/kg | 13 *(0)* | 13 *(0)* | 10 *(-23)* | 6.1 *(-53)* | 6.1 *(-53)* |
| Sink [a]* | l/day | *10.4 (0)* | *10.4 (0)* | *10.4 (0)* | *10.4 (0)* | *10.4 (0)* |
| Basin [a]* | l/day | 1.7 *(0)* | 1.7 *(0)* | 1.7 *(0)* | 1.7 *(0)* | 1.7 *(0)* |

[a] CLG (2010) [b] Hunt et al (2012) and Zadeh et al (2013) * User behaviour included.

**Table 2:** User behaviour (italics show change from design case S2)

| End Use | Units (P – person) | Design Case | | | | |
|---|---|---|---|---|---|---|
| | | S1 | S2 | S3 | S4 | S5 |
| WC | Flushes/day | 4.42 *(0)* | 4.42 *(0)* | 3.31 *(-25)* | 1.90 *(-57)* | 1.90 *(-57)* |
| Shower | Minutes/day | 8.74 [a] *(+100)* | 4.37 [b] *(0)* | 2.93 [c] *(-33)* | 2.19 [d] *(-50)* | 2.5 *(-50)* |
| Bath | Capacity/day | 0.11[e] *(0)* | 0.11 *(0)* | 0.06 *(-50)* | 0.05 *(-58)* | None *(-100)* |
| Dishwasher | Use/p/day [f] | 3.6 *(0)* | 3.6 *(0)* | 2.4 *(33)* | 2.4 *(33)* | None *(100)* |
| Washing machine | Use/p/day [f] | 2.1 *(0)* | 2.1 *(0)* | 1.6 *(-23)* | 0.99 *(-53)* | 0.99 *(-53)* |

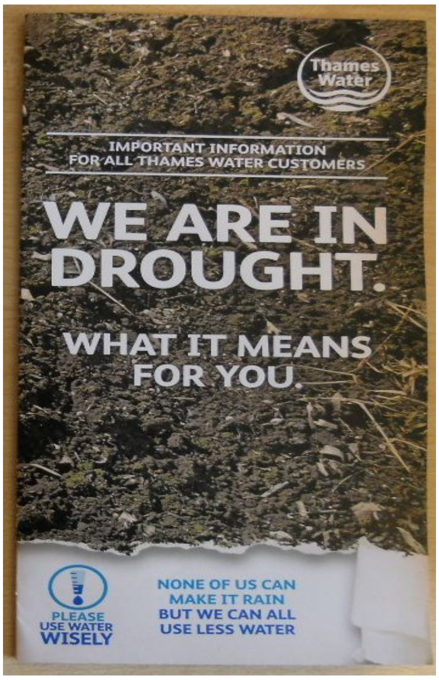
[a] 9.8 min shower (8 in 9 days); [b] 4.9 minute shower (8 in 9 days); [c] 3.3 min shower (8 in 9 days); [d] 2.5 min shower (8 in 9 days); [e] Bath (full bath, 1 in 9 days); [f] ps – place setting; [f] p – person.

For example, a 25% reduction in water use for WC flushing (which matches that achieved in S3 in Table 1) is achieved through a 25% reduction in the number of flushes made per person per day, from a UK average of 4.42 to 3.31. In this case it is assumed that the technological efficiencies remain constant and operate at the same level as S2 in Table 1. Likewise a 100% increase in water use from showering is made by doubling the time spent in the shower rather than adopting a power shower. This aspect is underplayed within the assumptions made in the CSH (and other similar) methodologies as are the separate, yet equally strong influence(s), of *'duration'* of use and *'frequency'* of use. These can operate individually or in combination for each water use (Zadeh, Hunt and Rogers, 2013). For instance, when considering showering both will influence water use whereas when considering bathing only the later (along with what level the bath is filled to) will influence water use. In case S2 some 58.8 litres of water per shower are used (i.e. 52.4 litres / shower / day, assuming a shower is used 8 in 9 days) which, on the face of it, would appear more sustainable (in terms of reduced water consumption) than adopting a bath where 230 litres per bath are used - if it is full (i.e. 25.3 litres / bath / day if used 1 in 9 days). This misses the subtlety that a bath could be used 1 in 18 days rather than 1 in 9 or a shower could be used every other day (i.e. liveability is different depending on the end-user). Ironically, if a 230 litre bath were filled to a quarter of its capacity a lower daily use figure would be achieved (i.e. 57.5 litres / bath /use) even if the bath were used every day. In essence therefore, this suggests that the user perhaps should not be accredited only for adopting a smaller bath, they should however be accredited for the quota of water which they allocate for daily personal washing (either through bathing or showering – the choice being theirs alone). The choice of technology and user behaviour is then accredited equally. This allows those that cannot afford a change in technologies to be accredited also - for more 'sustainable' consumption. Likewise it incentivises those that can afford a change in technology to consider their long-term behaviour; avoiding consumers buying a water efficient shower that uses half the water of the old shower only then to use it for twice as long.

User behaviour, unlike technologies can be highly variable, so perhaps the achievement of the highest performance levels shown in Table 2 would require additional technologies to incentivise, help (or nudge) a 'step-change' in users behaviour. These are available or perhaps could be designed in. For example, 4 minute timers (Figure 2) were given out freely in the South East of England by Thames water during the early drought in 2012. Although, now the drought has subsided how many of these are still being used today – moreover did users really stick to four minutes? So perhaps in this case technologies could be used to influence more strongly user behaviour.

A sensor could 'time-limit' or 'volume-limit' bathroom water supplies ensuring set volumes of water flow from taps, showers and baths. This does not prevent the user overriding them – nor should a democracy should seek to limit free will. In a modern society this is more about making people aware of their water using behaviour and facilitating, rather than enforcing, a change. Coin operated showers, for example on camp sites, already operate in this way, although for domestic adoption perhaps the technology would benefit from electronic 'bleeps' according to the minutes taken in the shower, or perhaps green, amber and red light gauges so the water does not run out before all washing is completed. Even timing devices for sinks (i.e. timed for flows of around 10 seconds – adjustable by the installer) already exist in office / hotel settings and therefore it is not beyond the realms of possibility that they could be introduced in a domestic setting.

**Figure 2.** Incentivising changes in 'user-behaviour' for London during the 2012 drought.

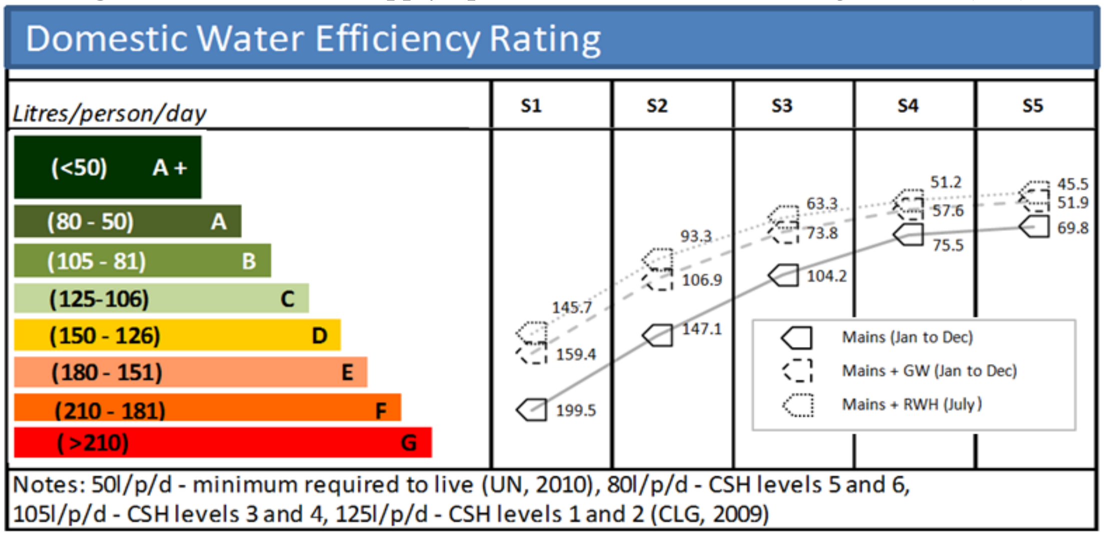

The question remains as to 'how low could one go to ensure resource security whilst maintaining user comfort and performance levels, i.e. liveability for the user and for the city of the future?' More importantly can we think outside the box when it comes to future user behaviour – will it be significantly different from what we currently know and do? In most cases the thinking can be prompted by a 'what if?' question. For example, 'what if' we wore clothes for twice as long between washes – facilitated by manufacturers engineering stay clean clothes? 'What if' we produced significantly less washing-up – by eating out more or by ordering ready cooked foods? These user changes need to be considered in parallel to technology changes and any benchmarking system should allow for this. For some water uses it might be deemed impossible to reduce down the frequency of use below UK average values, for example WC flushing, as this is related to a natural necessary bodily function – in terms of urine we all produce around 2.5 litres/person/day. Or perhaps it prompts the more pertinent question of how do we reduce flushing, if it is not through a step-change in technology? In cases of drought in Brazil a television advertisement campaign urged water users to urinate in (their own) showers whilst showering to conserve water (Mangan, 2009). For a western society this may on the face of it appear shocking, but it is not dissimilar to the mantra *'when it's brown we flush it down, but when it's yellow we let it mellow*' passed on to children who live in areas ridden by water droughts and rationing (Green ideas, 2012). This paper does not suggest we all adopt these actions, far from it, however it does suggest that by thinking along these lines more inventive solutions for the way we consider sanitary waste within cities. Perhaps a dual track approach could be adopted within the home. Offices already separate urine flushing (for males) from WC flushing (for solids only). After all the volumes of 'held' water within toilets in urban areas (i.e. in a U-bend - required to keep out odours out; and in a cistern - to flush) is not inconsiderable. What if, for example, the design brief for a city is to ‘design’ these out how might this be achieved? Perhaps some type of holding mechanism for urine that is automatically flushed once a day? This is eminently possible, not least if urine became a more valuable resource? Research is already looking at it from an energy supply perspective (Ieropoulos et al, 2011). The answer is not clear cut, although pneumatic systems are an option, and there could be numerous other options - available or yet to be thought of. One important consideration obviously would be upon outward flows to the sewerage system and this would need to be investigated further also. The point here is about moving us beyond what we now or accept as the ‘norm’ and to provide us with a robust band-rating (including benchmarking) framework that allows for monitoring and measurement along the way. The role of user behaviour and technological efficiency (in isolation) is used here to exemplify the role of the proposed band rating system, a more in depth analysis of these highly influential factors (in isolation and conjunction) can be found in Zadeh, Hunt and Rogers (2013). The way in which water using behaviour and technological efficiency adoption changes by age, gender or demographics is unclear and perhaps this is a research challenge to be answered.

## 3. Influence of supply side options on band rating

### *3.1 Mains vs Rainwater harvesting (RWH) vs greywater recycling (GW).*

An accompanying strategy to reducing the demand-side flows is to complement supply-side flows with alternative locally available supply sources such as Rainwater Harvesting (RWH – collection of rainwater from impermeable surfaces for use in WC flushing and washing machines Nolde, 2007) and / or Greywater recycling (GW – water collected from baths, showers and basins for use in WC flushing and first rinse on washing machines, Eriksson et al., 2002, Leggett et al., 2001). In CSH accreditation Levels 5 and 6 require adoption of GW recycling (for WC flushing) and / or RWH. Some well known UK examples (e.g. The Lighthouse, Kingspan 2009), in an aim to reduce potable demands further have adopted both. In this section all three approaches are considered for all of the design cases (S1 to S5 in Figure 1). Herein each domestic property is assumed to have a pitched 50m$^2$ roof and to be located in the NW region of the UK, an area of high average rainfall (1268 mm/yr). An average of 2.4 occupants per household is assumed (Macrory, 2012) and internal demands only are included (see 2.2.2 and 2.2.3 for sensitivity analyses of location, occupancy and inclusion of external gardening demands). The tank(s) are sized according to British Standard BS 8515 (BSI, 2009) - this uses the lesser of 5% annual rainfall and non-potable demands. It is assumed that an empty tank is installed in January, it has been in operation for at least 12 months, and is filled / emptied assuming a 'yield before spillage' approach (Mitchel et al., 2003; Mitchel, 2005; Ward et al, 2008). The rainfall data is taken directly from the met-office (Met Office, 2013) and uses average monthly values of rainfall to calculate a daily average supply of rainwater. [Stored water dictates available supply whilst spare capacity dictates flash flood protection, the influences of which can are reported by Hunt et al (2012a, b).] Consideration of the RWH supplies in July is adopted – this being the driest average month within the UK. Figure 3 shows the impact on water using performance on the band rating. [N.B The band rating system presented here relates to the total daily volume of mains water consumed and not the total volume of water consumed.]

**Figure 3.** Influence of supply options on demand band ratings in NW (UK)




Compared to a mains only supply an additional GW supply will reduce mains water requirements by between 20% (S1) and 25% (S5) year round, whereas an additional RWH supply can reduce mains water requirements by between 35% (S1) and 37% (S5) placing demands in the A+ band for the S5 design case. The band ratings achieved were best (i.e. lowest mains water demand) where internal demands were lowest. In all cases the RWH system out-performed the GW system due to an abundant supply of rainwater throughout the year in the NW. [N.B. Moving from S1 to S5 there are changes to GW in terms of both supply and demand – S5 has the lowest production of GW, although it also has the lowest demand. The reverse is true for S1, the power shower produces a significant additional supply of GW as compared to S2 and yet the demand for GW in each is identical.]

### *3.2. RWH specific influences:*

In CSH credits are awarded for adoption of GW or RWH, however no consideration of the factors that can affect their current and / or future performance is considered. This means that two systems adopted in the same (or different) locations may perform very differently and yet receive the same amount of credits. In this paper the impact on RWH systems of roof size, location (rainfall), and occupancy on band rating are shown in Figure 4a to 4c respectively and are discussed below. For direct comparison the impact of each influence on a GW system is discussed also.

#### 3.2.1. Roof size

The influence of roof size on water using performance for each of the design cases is shown in Figure 4a. Increasing the roof size improves the band rating that can be achieved. However, a limiting value is approached as the catchment area matches that required for meeting internal non-potable demands. This means an RWH system adopted with an undersized roof will result in a reduction in the band rating that could be achieved. This under-sizing may have occurred due to limitations of available roof space or the long term influence of overhanging buildings, trees, for example. Similarly over-sizing the catchment area, say to 75m$^2$ brought about no benefit in terms of band rating in all design cases; once non-potable demands are met any excess rainwater is surplus to requirements and (where available capacity exists) is stored or directed to the wastewater system. A surplus of stored water acts as a buffer to ensure the best band rating is achieved. A performance band of 'A+' (45.5 l/person/day) could be achieved in design case S5 with a roof size of 50 $m^2$ and 25$m^2$, although this dropped to band 'A' (53.9 l/person/day) for a 12.5 $m^2$ roof. For design cases S4 and S5 a catchment area of 50$m^2$ could be considered oversized, as the non-potable demands are low, half of this would have been more than adequate to meet the specified internal demands. All of these considerations are beyond the scope of CSH and highlights the requirement for benchmarking longer-term performance. Roof size has no influence on the supply of GW within a domestic property hence, not surprisingly there is no influence upon the band rating previously achieved in Figure 3. Hence an additional plot is not required.

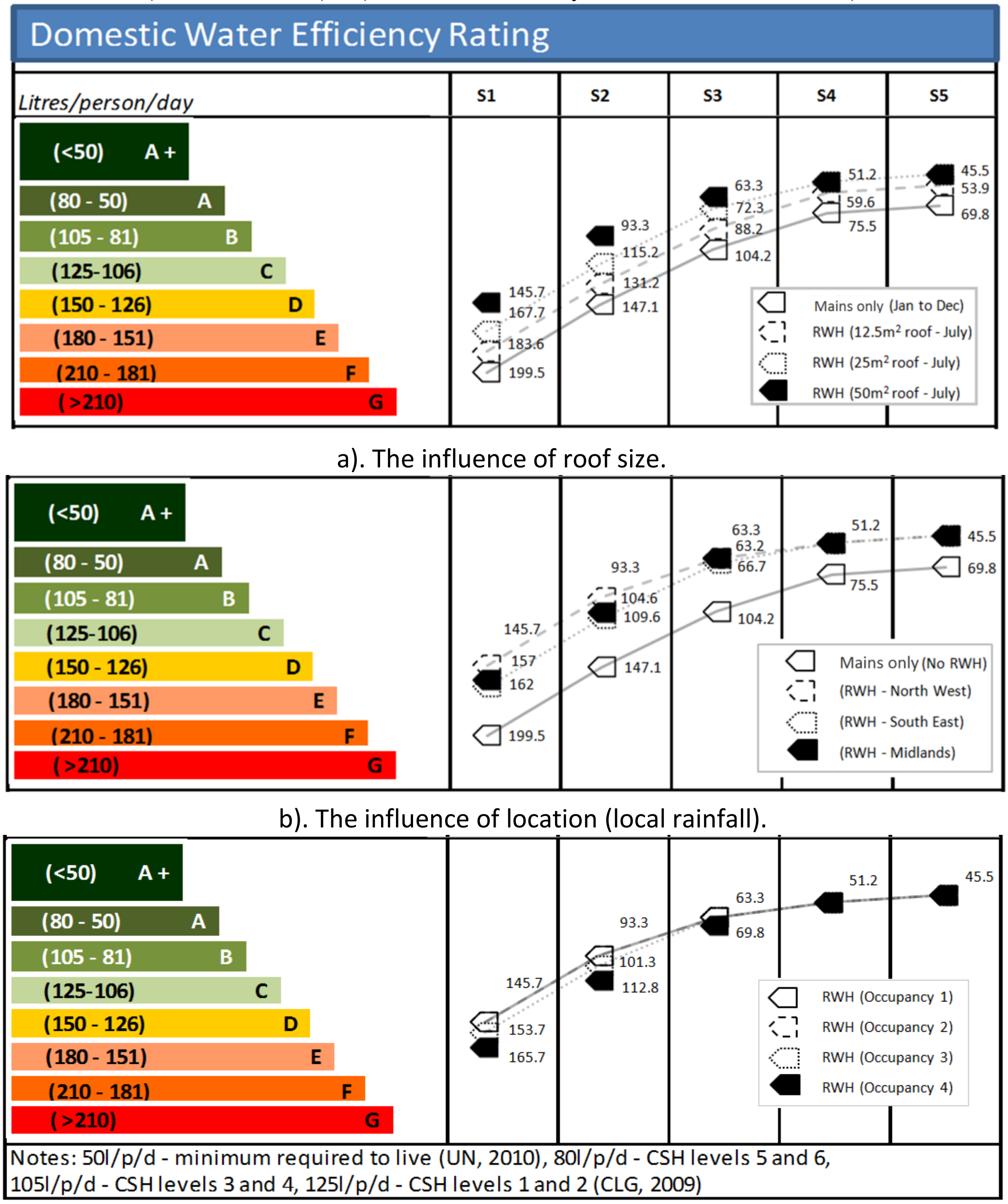
3.2.2. Geographical location: rainfall

The influence of rainfall on RWH system performance in three different UK locations (Midlands, NW and SE) is shown in Figure 4b. The best performance levels were achieved where rainfall was highest (i.e. 1268 mm/yr in NW) and worst performance levels were achieved where rainfall was lowest (780 mm /yr in SE). In all cases RWH contributed to reducing mains water demands and improving the benchmark that could be achieved. Most notable was the fact that a performance level of 45.5 l/person/day could be achieved in design case S5 in all locations. Location becomes a more influential factor as the internal demands begin to increase (i.e. S3 to S1) and in these design cases RWH supplies can no longer meet demands. It can be seen that the performance of any RWH systems is directly related to rainfall, which is region specific, and this impacts directly on the levels of performance and band rating that could be obtained, lowest in SE and highest in NW. Currently this is not a consideration for CSH. Once again GW production is not influenced by regional rainfall patterns hence there is no impact upon the levels of performance achieved in Figure 3.

3.2.3 Occupancy rates

Figure 4c shows the influence of occupancy rates (1 to 4) on band rating. When 1 or 2 occupants are present performance band rating appears to be unaffected for all design cases. When 3 or more occupants are present the band rating of S4 and S5 are also unaffected achieving the highest performance levels (45.5 and 51.2 l/person/day respectively). However, when 3 occupants are present the water using performance of S1 (8% increase in water consumption, i.e. from 145.7 to 153.7) and S2 (12% increase in water consumption, i.e. from 93.3 to 101.3) is worsened, and this is worsens further as one extra occupant is added – moreover the performance in S4 then becomes worse also. These performance levels are further decreased when 5 or more occupants (not shown) are included, although the % increase becomes less noticeable for each extra occupant added. As internal demands and GW supplies are measured per person any change to occupancy rates do not affect the water band rating that can be achieved. Occupancy rates are currently outside the scope of CSH and it appears that as long as water consumption values per person are low, i.e. CSH Levels 5 and 6, occupancy is not influential, however for CSH Levels 1 to 4 some influence will occur.

**Figure 4.** Influences of RWH non-potable supply option on water band ratings in UK (Location NW (UK) and month of July unless stated otherwise)




a). The influence of roof size.

b). The influence of location (local rainfall).

c). The influence of occupancy.

*3.3. Inclusion of external (gardening) demands.*

It has been reported that households who enjoy a 'green' environment, display high interest in garden and gardening, and as a consequence use more water externally (Syme *et al.,* 2000). In CSH the demand for gardens is specified as 5l/person/day (CLG, 2009). Unfortunately, as an average figure, this takes no account of influencing factors such as time of year, garden size (e.g. the average garden size in the UK is estimated to be anywhere between 50 $m^2$ and 100 $m^2$ – although considerably lower in new build in dense urban areas) water supply (i.e. mains and/or GW and/or RW) and geographical location that could impact considerably on water performance and band rating.

In this section these are considered by estimating a garden watering demand based upon a generic model developed by FAO (1986) by which monthly climatic data are translated into a soil water balance for a given month (Downing *et al.* 2003, Roebuck, 2007). The availability of water for any given plant type (assumed here to be grassland, flowers and shrubs) is a function of available soil water (root zone for grass is relatively shallow, i.e. <50mm), rainfall and evapo-transpiration (ET) for each plant type (calculated according to Blaney Criddle method, see Doorenbos and Pruit, 1992). ET is influenced by temperature which is, as rainfall, location specific. In this section the influence of time of year on water demands and performance is assessed (3.3.1) following which their sensitivity to changes in garden size and location (3.3.2) are considered. In section 3.3.3 the added influence of occupancy is investigated.

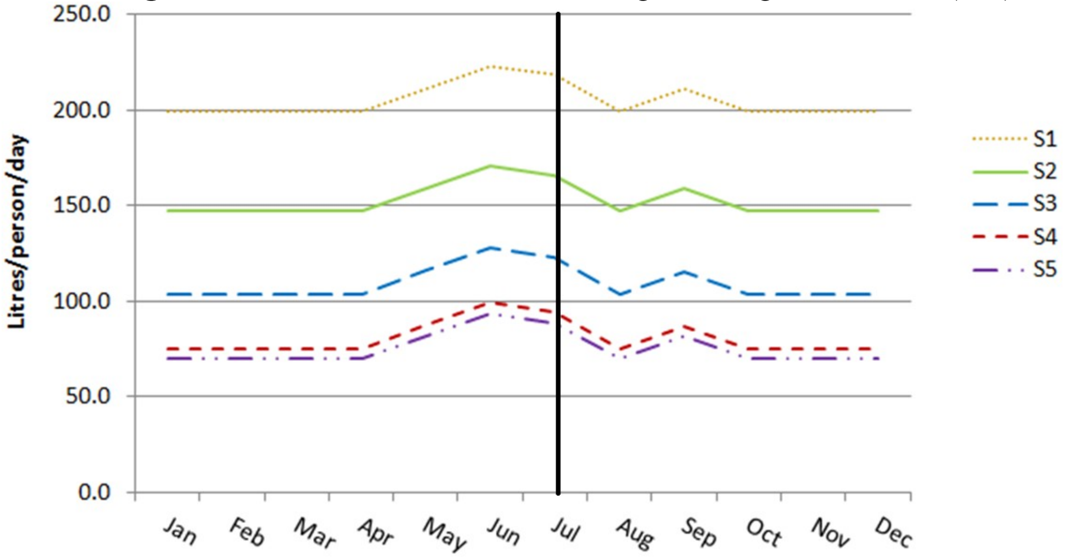
3.3.1. Influence of time of year

Figure 5a shows the water demands throughout the year for each design case. From where it can be see that demands increase considerably from April through to October (i.e. the summer growing season). The gardening demands are identical irrespective of whether the design case adopts water efficient appliances for internal demands. The breakdown of demands for each design case in July are shown in Figure 5b from where it can be seen that gardening demands amount to <10% for design case S1 and almost 20% for design case S1. This is important as it means that although a domestic property might perform to a CSH level of 6 (i.e. 80l/person/day – band A) during winter months it may only perform to Level 3 and 4 (105 l/person/day or lower band B to C) in summer months – this variability is not considered in CSH. Garden demands are typically highest when temperatures are highest (evapo-transpiration is temperature dependant) and rainfall levels are lowest necessitating garden watering. This becomes particularly problematic when hosepipe bans are in place in summer months significantly reducing the ability of urban householders to successfully grow vegetables unless alternative watering measures are adopted.

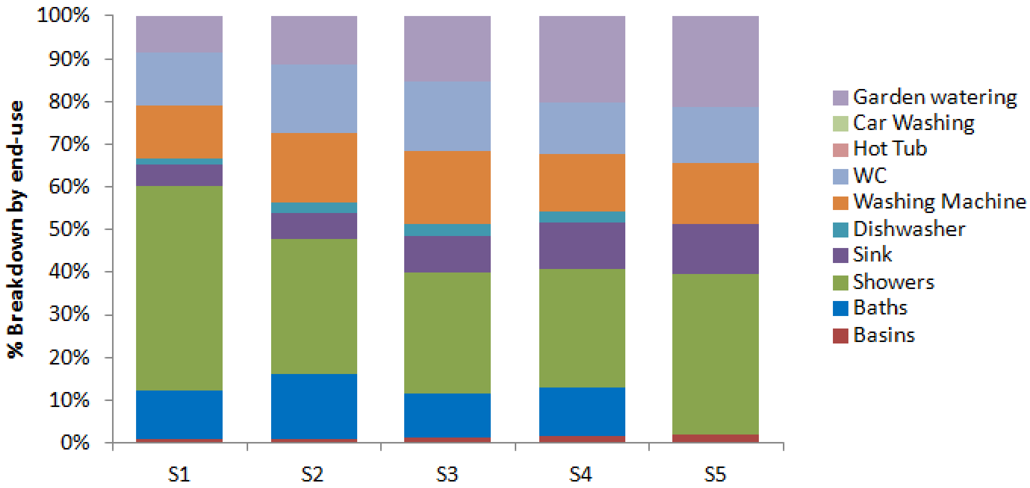
The difficulty for benchmarking occurs when non-potable sources being used to meet internal non-potable demands are insufficient to meet total non-potable demands (i.e. internal + external).Within this paper it is assumed that potable demands are met through mains water and non-potable demands for each design case (with the addition of a 50m$^2$ garden) could be met in one of four different ways as listed below:

- Option 1 - Mains only supply, for all non-potable needs (i.e. no RWH and / or no GW);
- Option 2 - GW, for WC flushing, first rinse on washing machine and gardening;
- Option 3 - RWH, for WC flushing, washing machine and gardening;
- Option 4 - RWH and GW; GW for WC flushing & RWH for washing machine and gardening.

**Figure 5.** Water demands when including a 50m$^2$ garden in NW (UK)




a) Yearly water demands.

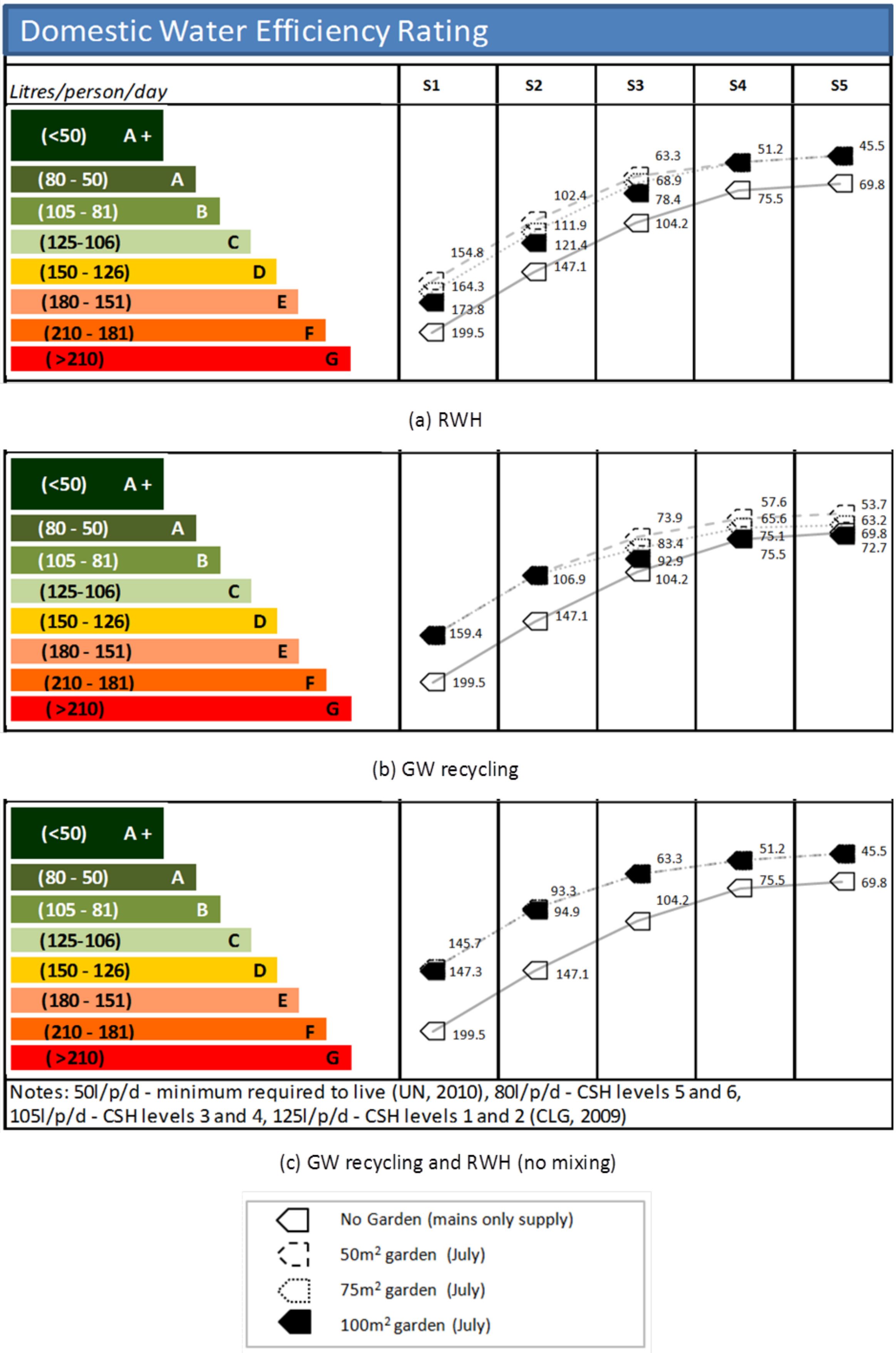



b) % Breakdown by end-use (July – relevant to thick black line in Figure 5a)

3.3.2. Influence of garden size (and location)

Figure 6 shows that even in the presence of 50, 75 and 100 m$^2$ performance and band ratings can be improved (through adoption of RWH or GW systems supplying non-potable water in isolation or in combination) beyond those for the base case - a domestic property without a garden supplied by mains water alone. For an RWH only option (Figure 6a) the band ratings achieved in S1 and S2 were not influenced by any changes made to garden size and matched those achievable in the absence of any garden demands when RWH is adopted (Figure 4). However, as internal demands increased (i.e. from S3 to S1) so the mains water using performance was influenced. The most notable influence was for S1 where a doubling in garden size (i.e. 50 to 100m$^2$) caused demands to increase by 12%, although the band rating remained as E. For a GW only option (Figure 6b) the effects occur in reverse to a RWH only option, i.e. the benchmarks are not influenced by variations in garden size in design cases S1 and S2 where lower demands exist. However in design case S5 the increase in garden size from 50 to 100m$^2$ results in a 35% increase in mains water demands, although no change in band rating A.

**Figure 6:** Influence of garden size on band ratings for various non-potable supply options in NW (UK)



However, in design case S3 increasing the garden size from 50 to 75m$^2$ causes a band rating change from A to B. The RWH and GW combined option allows for the highest band ratings to be achieved in all design cases and these are little influenced by changes to garden size.

In Figure 7 the impact of a change in location from NW (UK) to SE (UK) is very noticeable; an increase in garden size increases water demands and influences band ratings for all design cases with any supply option. The most noticeable impact here is in S1 where a band rating change from A to C occurs as the garden is increased from 50 to 100m$^2$. In all cases the performance is two to three band ratings lower than that achieved in NW (UK) and significantly less than the base case. The most notable exception to this is the adoption of a GW recycling system (Figure 7b) in S1 (where approximately 20% less water use is achieved than the base case for all garden sizes considered) and S2 (where 20% and 6% less water use than base case are achieved respectively for 50 m$^2$ and 75m$^2$ gardens). The dual approach system (Figure 7c) offers better performance than individual approaches in S3, S4 and S5. However, the performance in S4 and S5 is worse than an individual GW recycling system, although better than an individual RWH system. These subtleties were not apparent in the NW and certainly are not considered in CSH accreditation.

3.3.3. Influence of occupancy (and location)

The band ratings for an RWH supply are little influenced by occupancy rates (Figure 8a) and this should not be surprising as the total garden demand and total RW supply remain constant. The slight deviations from the baseline are due to subtle changes in internal non-potable demands within design cases; the influence being most noticeable in S1 where non-potable demands are higher than RW supplies. In the case of a GW supply the total garden demand once again remains constant and is relatively unaffected by occupancy numbers (Figure 8b). This is as expected because the garden demand is unchanged and GW supplies will increase relative to occupancy (i.e. four occupants produce four times as much GW as one occupant) – hence water using performance will not be impacted provided enough occupants exist within the household. In this example GW supplies from one occupant are insufficient to meet non-potable demands and hence the performance is impacted; the influence being most noticeable in S5. When both RWH and GW are used (according to the system rules outlined earlier) the lowest water use and hence highest band ratings can be achieved (Figure 8c). The advantage here is that occupancy no longer becomes an influential factor and that is because a dual supply produces more than enough non-potable water to meet demands in NW (UK). In Figure 9 the impact of a change in location from NW (UK) to SE (UK) can be seen. The influence of occupancy numbers is far more noticeable in SE (UK) than NW (UK). In all cases performance and band rating improves as occupancy numbers increase. The impact of a single occupant on performance of the GW system (Figure 9b) is more pronounced in SE (UK) than NW (UK); most notably in S5 where the water use for a single occupant is 120% larger than for 4 occupants. For NW (UK) this was 47% larger (Figure 8b). Providing the occupancy rates are 3 or less a dual system will offer better water use performance and band rating than a RWH system in the SE (UK). However, if the occupancy rate is 4 or more the best water use performance and band ratings are achieved with a GW supply. This is not self-evident in absence of the analyses performed here.

**Figure 7.** Influence of garden size on band ratings for various non-potable supply options in SE (UK)

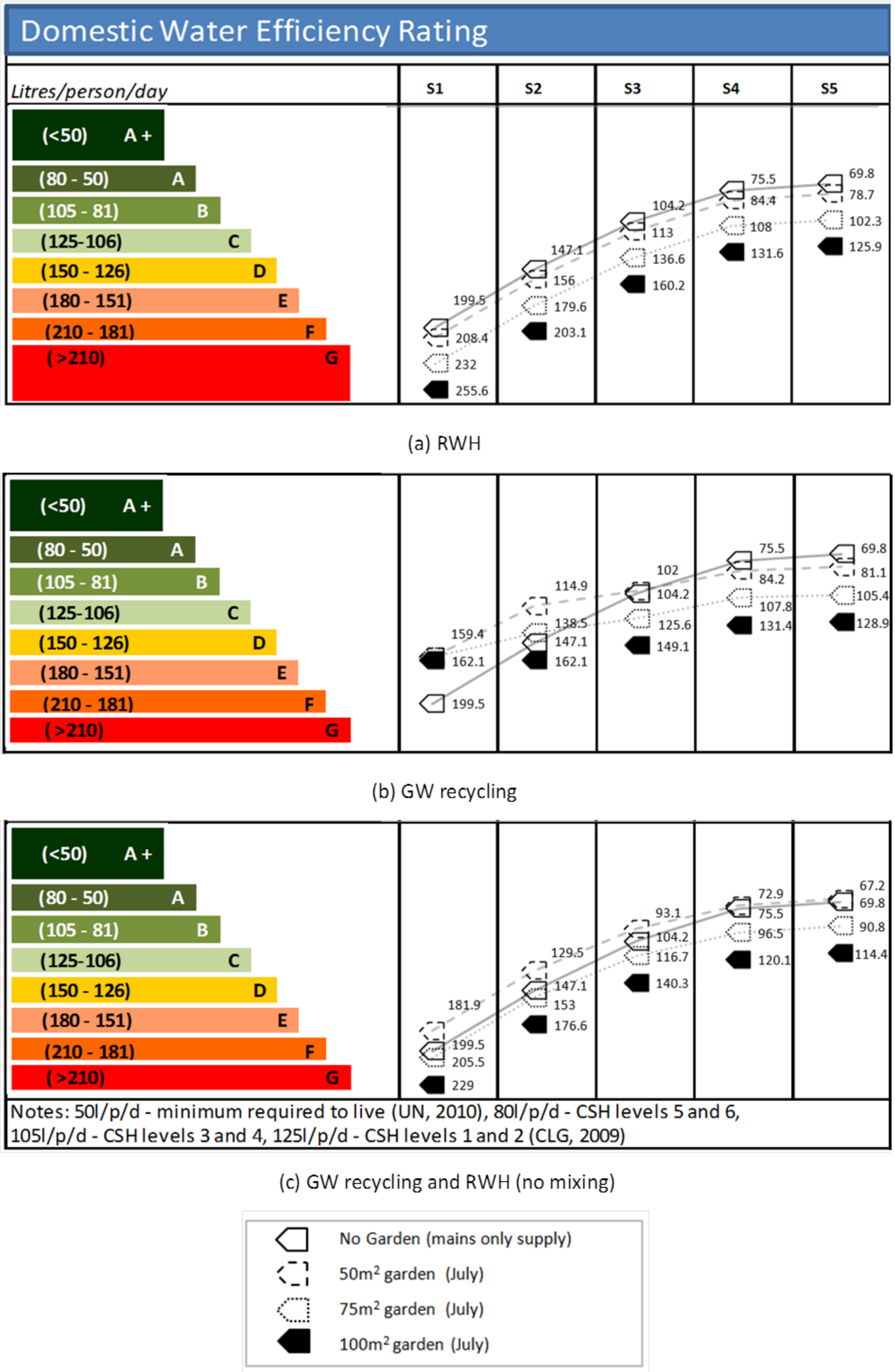


**Figure 8.** Influence of occupancy rates and non-potable supply options on band ratings for a 50m$^2$ garden in NW (UK)

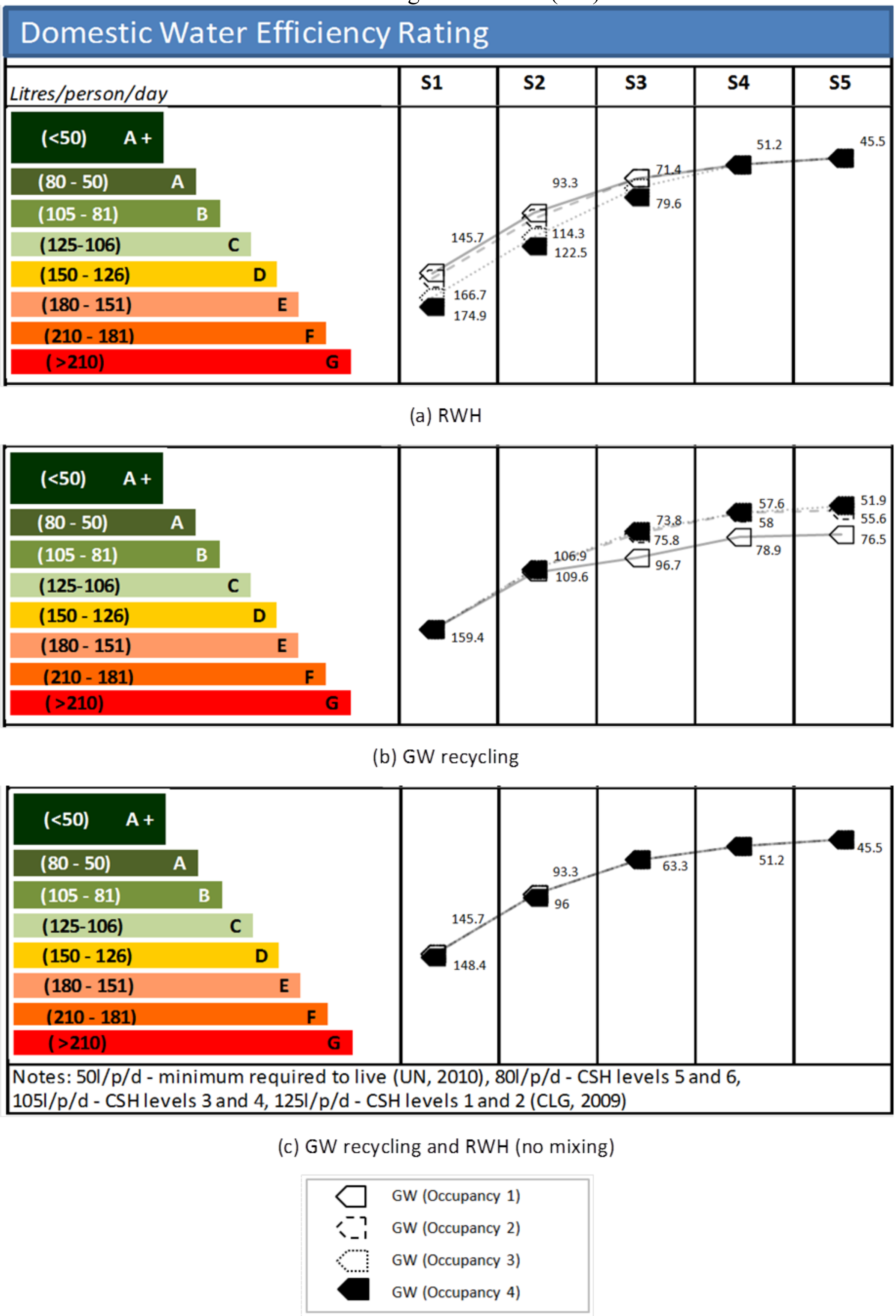
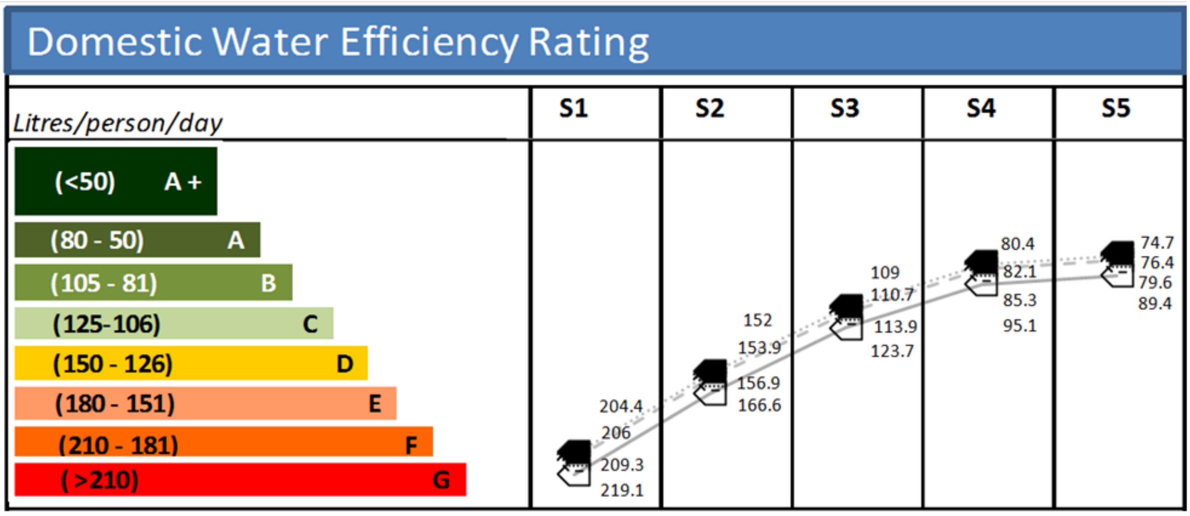
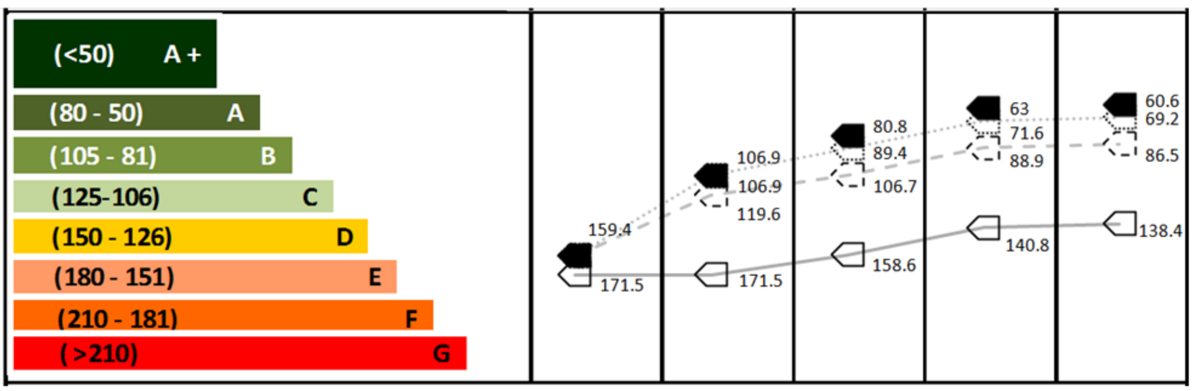


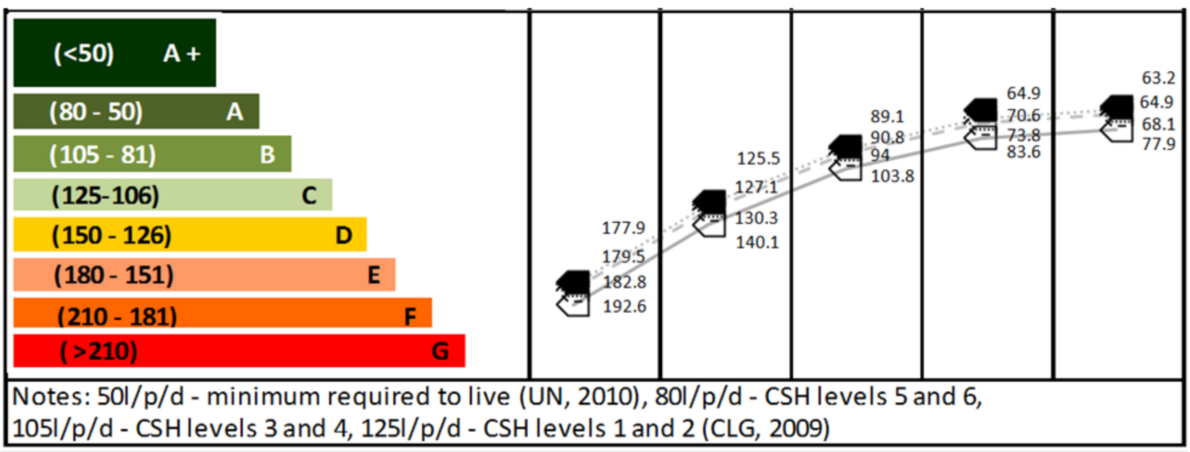
**Figure 9.** Influence of occupancy rates and non-potable supply options on band ratings for a 50m$^2$ garden in SE (UK)




(a) RWH




(b) GW recycling




(c) GW recycling and RWH (no mixing)

## 4.0 Discussion:

The analyses performed here have highlighted the sensitivity of the proposed band rating system to a range of influences and discussed the relevance with respect to the existing code for sustainable homes where credits are awarded (sometimes prior to occupation of dwellings) without consideration of longer-term performance. The proposed benchmarking system appears to fill this shortfall. This paper does not suggest that CSH should be replaced - its limitations just need to be understood. In many respects it does what it set out to do (i.e. crediting the adoption of water efficient technologies) moreover it has buy-in from house builders and home owners alike. The proposed benchmarking system can be used alongside CSH certification (the two integrate seamlessly) giving the users a better idea of how the household is performing in terms of its longer- term water use.

Whilst this goes a significant part of the way to achieving improved water performance within cities it will require consideration within other key areas, namely policy and economics, a brief discussion of which is given below.

### *4.1. Policy*

Policy could be used to ensure that a water certification (using the proposed band rating system) for domestic buildings is adopted. Domestic properties are metered and therefore band ratings for water could be used within existing billing systems giving the user an idea of their water use and how it relates to a specified standard (and other water users). When used alongside smart metering (advocated by existing UK policy and very much aligned with CSH philosophy, Nicholl and Perry, 2009) users will begin to understand how each water use impacts upon the total water demand for a household. The role of occupancy has been shown to be influential on daily water use and band ratings or benchmarks that use the ‘per person’ measure. Including this finding within policy is likely to be fraught with difficulty. Particularly so when considering the example of garden watering where the current value of 5l/person/day significantly underestimates actual daily demands and the influence of location, occupancy, rainfall, temperature, plant type and garden size. Perhaps the daily banding should be accompanied by a yearly benchmark (per household) that allows for incorporation of fluctuations throughout the year.

On the supply-side perhaps systems should not be accredited just for their adoption more for how non-potable needs are met through non-potable water supplies – thereby reducing consumption of mains water (see Lombardi et al, 2012 for a description of the efficacy of water resilient solutions in city designs). Policy could stipulate that **<u>all</u>** non-potable demands are met through non-potable supplies. In this case a simple banning of outside taps would not be inappropriate. In addition policy could advocate the adoption of dual approaches (RWH and GW) for meeting non-potable demands – this paper has shown the significant advantages in terms of flattening the peaks and troughs in daily water-using performance, in particular where gardens are watered in summer months. This is particularly important if homeowners are being influenced to be more self-sufficient in home-growing and ‘greening’ city centres where roof space is at a premium. One policy (or accreditation requirement) might suggest that all internal non-potable demands are met through GW and all outdoor demands such as gardening, but also car washing, are met by harvested rainwater. Green roof gardens (not least with food crops) or green walls can then be adopted only where they do not produce and additional pressure on city centre water supplies.

*4.2. Economics*

Economics (i.e. the costs to the water company and the costs to the consumer) is an important driver within the water sector. The water company want to supply clean water whilst maintaining a profit for shareholders, whilst the consumer wants to minimise the outlay on water resources. The role of the policy maker (and water regulator) is to track water pricing and ensure that tariffs incentivise efficient, rather than profligate, water use whilst managing to alleviate 'water-poverty'.

Payback periods for investment in water efficiency measures or localised supplies (e.g. RWH/GW) are highly influential in terms of whether the investments are small-scale (i.e. consumer invests within their property) or large-scale (i.e. city scale investment). Payback at small-scale is well reported within the literature, although the feasibility of making an economic investing in a non-potable city network allowing **all** non-potable demands to be met through non-potable supplies is not. Such a network would seek to make the links between producers and users of non-potable water, for example a producer may have a large roof space and capture rainfall yet have very low or no non-potable demands (e.g. a warehouse). Whereas a user might have high non-potable demands yet have low supplies (e.g. offices). Further work is needed in this area. In addition the impact of the highly influential parameters highlighted herein should to be investigated. In all cases transport and treatment of water will have an additional cost that needs to be factored in (Zadeh et al, 2013). As water efficiency measures are improved the requirement for non-potable supplies within buildings (be it domestic or other) decreases and hence the payback period will become longer, although if external demands, in particular gardening (but also vehicle washing) are included payback periods will improve significantly. In addition home urban growing of vegetables could reveal economic (and health) benefits. [The water demands are broadly similar to those for grassland and shrubs analysed here (in fact the Blaney Criddle assumes grassland as the highest base case against which 'crop' water demands are calculated.] This benefit comes from the reduced cost of going to the supermarket in addition to the reduction in 'embedded' transportation (and importing) costs which are not insignificant – this argument strengthens further when carbon costs are factored in. However, there is the important question of whether we will, in the not too distant future, have enough water to go round within a city centre landscape for all these different 'internal' and 'external' demands, even with the addition of non-potable supplies? If we do not then the 'value' and 'cost' of water will increase substantially. [Interestingly in Southern Ireland Domestic water rates were abolished in 1997 and without them there has been little to incentivise the 'value' of water. With their imminent (re)introduction in January 2015 it is interesting to see how its 'value' has returned.]

The benchmarking system presented here could have a role in improving users value of water as it could align directly with a pricing structure - rewarding 'non-profligate users' (i.e. those that reduce consumption of mains water) whilst alleviating 'water poverty' (i.e. band A+ use could be for free with price tariffs increasing for each band rating). The big users (band G) would pay the most; this aligns itself completely with incentivising CSH and drives home the ethos of 'the polluter pays' principle – which is definitely the case when water related carbon costs are included. Therefore even if peoples water use was not changed through such an approach (See Zadeh at al., 2013) any increase in revenue could be used to invest in additional water supplies such as non-potable networks.

There may produce difficulties for water companies in knowing exactly what the total daily water use is per person based on metered records alone. Although information on occupancy rates does form part of the council tax assessment system - although loopholes might then exist where occupants are registered 'at home' and yet live away for substantial periods inadvertently bringing down the measured daily water usage per person. This merely illustrates the difficulties of introducing any 'fit-for-purpose' measurement/charging system that is far for all.

## 5.0. Conclusions

This paper introduces a new band rating system for measuring water-use performance in the UK. It has been shown to provide significant advantages when compared to existing accreditation systems like the CSH. Its generic approach and the various band ratings adopted are appropriate for use in any country and this lends itself well to ease of comparison therein. The novel approach to analysis which compares 5 options side-by-side helps significantly when making an informed assessment, not least when so many interdependencies are at play. The influences of demand-side and supply-side approaches were considered from where it was found that user behaviour has an equally, if not more influential role on demands than technological efficiency alone. Therefore it was suggested that any band-rating system (and associated accreditation for benchmarks) is best aligned with overall potable mains water consumption (as adopted here) and should not have a preference for either user technology or user behaviour. The choice of how reductions are achieved should be down to the end-user. The influence of location, occupancy rates, demand profiles and supply type were found to be highly influential on water using performance and yet these are ignored by accreditation systems like CSH. This is particularly true in summer months where water demands are highest and localised supplies (e.g. RWH) are lowest. The proposed 'A+' to 'G' band rating system holds great potential for allowing swifter progress towards achievement of a more sustainable 'city' water management where 'liveability' options and a valid form of water-use measurement are required. However, Social, Economic, Political Technical and Environmental influences (i.e. resource security and carbon reduction) will all have major roles to play in achievement of this aim.

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**Conflict of Interest**

The authors declare no conflict of interest.

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