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A Smart and Sustainable Concept for Achieving a Highly Efficient Residential Bathroom: A Literature Review

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Abstract:- Climate change has been one of the key issues confronting the world in the 21st century. Nevertheless, the concept of sustainability has become vital in battling excessive use of natural resources. Enormous consumption of water and energy in the bathroom has resulted in different unseen sustainability consequences and mostly, their nexus effect. The use of bathroom has been evaluated to be the major consumption of hot water in a residential residence and it is responsible for the significant water and energy carbon emission of about 539Kg every year in United Kingdom.

Smart and sustainable approaches are fundamental in achieving a highly efficient water and energy consumption in a domestic bathroom. Therefore, this paper aims to review and analyze how the challenge of a combined water-energy saving unit in a domestic bathroom will contribute to the overall sustainability of the house. The key finding shows that, it was necessary to adopt a holistic concept that will not jointly and interconnectedly improve the efficiency of water-energy nexus in the bathroom but also reduce size of the system component, carbon emission, when contrasted to optimizing the individual component in the bathroom. Subsequently, this paper also established that using smart technology and renewable energy system in a smart way are inevitable in achieving sustainability. The outcome of this study offers great insights to professionals, researchers and policymakers in achieving a highly efficient and low carbon bathroom that contributes to the overall sustainability of the household.

Keywords:- *Bathroom, Climate Change, Efficiency, Energy, Smart, Sustainability.*

I. INTRODUCTION

The impact of climate change is and will conceivably continue being an indispensable risk that specialists need to oversee and manage comprehensively right now. Sea levels are anticipated to rise, and harsh climatic conditions are presumably going to progressively normal [1]. Consequently, it can be evidently seen that climate change can have negative impact on water structure performance and environmental behaviors.

Studies from [1] have illustrated that because of growing populace and the obvious choices individuals have made in the manner water is utilized especially in the UK, over half of UK water supply is presently being distributed for household use. Hence, the efficient use of water demand is vital in a residential application. There is a general understanding that United Kingdom will apparently experience more warmer weathers and lower summer precipitation in the future [11,12,13]. Delayed precipitation, recurrent occasions of dry winters, and lack of ground water restoration on account of urban flooding, can incite drought conditions which raises the danger of water supply not satisfying quality guiding principle [11].

Water consumption in a household setting is the key part of mains water use. In the United Kingdom, a typical person consumes an average of 150 lit/day of drinking water for individual use [1]. The Government of United Kingdom has a goal of reducing consumption of water by 20% per person by 2030 [6]. Studies from [1] is focused on giving effective guidelines to curb water utilization from 150 to 130l/individual/day or likely 120l/individual/day subject to technologically innovative improvement and development.

Water-energy nexus are crucial environmental resources and are vital for environmental, economic and social improvement. Continuing worries about growing populace and increasing consumption of water-energy results in a connected or related environmental effect of extreme discharge of wastewater and water extractions. These extreme consumptions bring about GHG emissions which are accelerating research studies towards an improved incorporation of water and energy service. Enhancing and integrating water-energy systems will allow these worries to be dealt with in more financially efficient ways with increasingly sustainable results. Understanding the associations amid water and energy services is indispensable.

II. THE BATHROOM SYSTEM

A bathroom can be defined as an environment where sanitary A bathroom in simple terms is an environment, a place or room where bathing and sanitary takes place, it comprises of shower, toilet, sink/basin notwithstanding if it includes a bathtub or not. Bathrooms can be classified as private or shared depending on the number of individual users. For example, a bathroom can be an environment or a room that comprises more than a toilet, sinks and showers for the usage of more than an individual. According to [3], bathroom showers uses the most amount of water i.e. 33 percent in a single household with, 7 and 22 percent of water utilized for tap and flushing respectively, whereas in considering bathroom as a whole, a unit total of 62 percent of water is used.

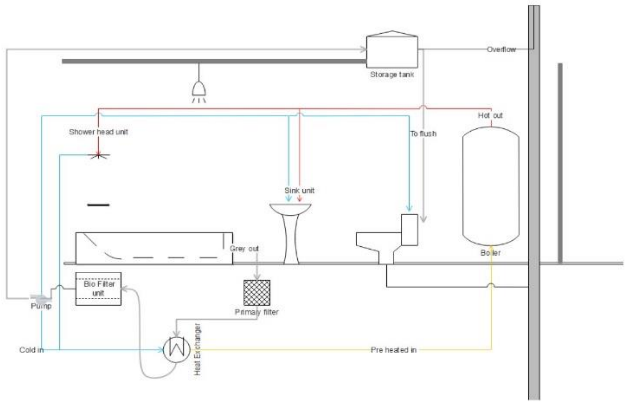

Fig 1:- A schematic of a standard bathroom unit

The above figure 1 clearly display an image representation and describes how a combined, operational and connections in a bathroom unit works. An incoming mains water are utilized for various events in the bathroom e.g. it is utilized in various kinds of showers (gravity feed, combi, electric etc.). The cold water is mixed with the hot water coming from the boiler to adjust the water from the shower to the user pre-set temperature generally between 40-43^{o}C [3]. This principle is applied to the basin water also.

Basin is another outlet that is connected to the shower pipe distribution network, and it is a frequent consumer of both cold and hot water. In recent years, basin taps usually have divided hot and cold-water channels whereas nowadays, mix taps are commonly used in most United Kingdom dwellings and that makes it possible for mixing cold and hot water in the tap and subsequent output from the tap is adjusted to the temperature desired by the user[7]

In the United Kingdom, a standard conventional bathroom is used for showering, bathing and basin tap usages. The incoming potable water from the mains to the bathroom is usually heated up by the boiler or heater, the heated hot water goes to a separate tank where the hot water is held up and circulated when and where required [1]. There are various issues with boilers, for instance, its inefficient energy usage, size, corrosion and extreme maintenance [22].

The quantity of energy used in the bathroom is mostly related with usage of hot water i.e. from water energy nexus from basins and showers (besides lightings). Energy is mostly used by bathroom appliances to heat up potable water to the temperature preferred by the user usually between (60 – 65^{o}C).

III. SUSTAINABLE ISSUES WITH BATHROOM

Recent studies from [4] emphasized the necessity of enhancing sustainability to reduce carbon emission in a business as usual (BAU) scenario to avoid the negative impact on the environment and jeopardizing the maintenance of economic and social developments. Likewise, studies from [5] have highlighted some key impact from excessive water and energy usage that cause difficulty with the environmental, social and economic sustainability, for instance water surface degradation due to surface overflow contamination flushing into the body of water, extra water removal affecting water body degradation and substantial maintenance cost with likely water supply upgrade and waste water treatment mechanism. Subsequently for this paper, the one key of objective of saving both water and energy is not only because of water shortages, decreasing environmental resources and upsurge in water demand, but additionally due to the quantity carbon emission that can be saved per litre of potable hot water in the bathroom. For example, in a standard bathroom, 3.186kJ which is equal to 0.4g of carbon emission outflow can be spared [3].

The utilization of intelligent and smart control device is vital in any localized system in saving water and energy in a bathroom unit. These smart control devices allow the end-user to be adapted to their desired pattern hereby increasing the system efficiency. This would be an important improvement to an integrated system in a domestic setting to save water and energy. In the household, water uses in the bathroom has the greatest likelihood of saving both water and energy. A standard bathroom that is retrofitted with combined water and energy saving systems does not necessarily include any massive renovation in the bathroom building and will mostly have a sustainable result having timely and maximum influence.

Studies from [6] illustrated that about half of showers in the UK use electricity in nearly all bathroom. Electric showers operate on smart flow control principle in preference to energy control system. The smart flow control (SFC) is comprised of a double heating element i.e. the user can alternate in manually switching one or both heating elements on or can as well decide to switch off the device. If the heating elements is switched on, the preheated potable water is delivered from smart flow controls. As principle is based around smart flow rate, the shower flowrate increases to reach the pre-set chosen temperature by the user approximately about 40-43oC, this give rise to

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an increase in pressure and water volume resulting into a temperature that can increase to a hazardous degree. Subsequently, because of the high danger of temperature, electric showers are not good in saving energy [8]. The domestic use of wastewater heat recovery (WWHR) system integrated with electric showers can bring about high energy efficiency if the design permits preheated water. Although, pre-heated water has been applied in boilers and mix-showers. The amount of energy saved is as a result of needing less energy to heat up the incoming potable water via the mains to a precise temperature if the feed-in water temperature is higher. In considering grey water recovering, key challenges are water storage setup, cost, water treatment quality, payback period and size of the system.

Enhancement of shower and taps distribution are indispensable possibility for technological improvement in the bathroom. Although numerous technological improvements have materialized in reducing flowrate while showering without affecting user comfort, however if the these improvements can be said for energy recovery and storage applications, then consequently preheated water for bath, showers and basin could have remarkable effect in accomplishing high energy savings in the bathroom [14]. This may happen fundamentally by diverting the preheated water to the potable water tap from the mains. The other course of action could be developing a mixer tap with three input channels (Cold, preheated and hot). The tap can then mix preheated and cold water for exact needs and whatever point required will draw high water temperature from the heater/boiler if needed.

The wastewater heat recovery in the market presently are based on instantaneous principle in its operations [8]. The reclaimed heat while showering is instantly utilized back in heating the incoming cold water from the mains going to the shower system to decrease energy usage. Additionally, since the wastewater heat recovery system are mostly horizontally designed, this reduces the system efficiency to be limited in its operation. The major issue with the vertical design is the high cost to retrofit as it needs modifications to the vertical sewage pipe core. Finally, another detriment to the wastewater heat recovery system is that they do not recover heat from using tap basins, therefore, incorporating other energy storage system could increase the wastewater heat recovery efficiency [8].

IV. ENERGY EFFICIENCY IN THE BATHROOM

Recent studies from [19], focused extremely on the increasing use of hot water in the bathroom and the related expense of heating up cold water from the mains. The studies subsequently also considered the potential methods for reducing the energy utilization in heating water and the related expense to delivered energy, by reclaiming the energy from black or grey wastewater that is discharged from the bathroom drain daily. This is dependent on the volume of heated water that is mixed with the of cold-water to give a temperature desired by the user. However, most grey water is diverted down the bathroom drain at a temperature between 35-55^{o}C. Considering that most hot water supply are often heated at a temperature from 10^{o}C to 60-70^{o}C by boilers or water heater, it is apparent that around 70-80% of all waste hot water from showring and basin taps goes down the drain [14]. Considering report from [8] having considered the financial potential for WWHR in contrast to waste heat availability and if the heat quantity can adequately meet the heating loads. The study concluded on saying WWHR may not solely meet the heating required in the bathroom without integration of renewable system and energy storage facilities.

The objective of heat recovery process is to increase energy efficiency by recovering and reusing of heat from any system or process that will somehow be lost. Different technological heat recovery products are now obtainable that can be utilized in the bathroom to reclaim greywater heat from showering activities. In greywater heat recovery process, the cold water coming from the mains flows via the HE (heat exchanger) where pre-heating takes place from the waste heat flowing down form the shower system. For instance, the water temperature that is appropriate for human body is approximately 40^{o}C. Water temperature between 5^{o}C -10^{o}C of is lost while showring. There are various waste heat recovery systems that are available that can reclaim up to 75% of the greywater heat flowing down the drain. This technique adds in reducing energy consumption and saving energy bills will likewise indirectly decrease the total equivalent carbon emission in the bathroom.

Subsequently, recent reviews from [10] have likewise estimated that about 80 to 90% heated water utilized for domestic and bathroom activities often goes down the drain channel as final output. Considering the thermodynamics of cooling and heating in relation to cost, it is projected that the cost in heating cold water is possibly one of the substantial costs in the household, particularly in the bathroom, big amount of this energy is being wasted by flowing the wasted heat down the drain channel and then to the outside environment. Reclaiming or recovering useful energy from showers and basin-taps are one of the potential approaches to improve bathroom energy efficiency while reducing related expense. Although the use of waste heat recovery systems and HE (heat exchanger) are not new technology or idea, however, because of its design limitation and installation, it has not been really utilized in a domestic dwelling and are for the most part employed on large industrial applications. Studies from [3], shows that a typical domestic dwelling emits about of 875Kg of CO_2 per year from energy utilized in heating up potable cold water in almost every home. This discharged CO_2 is relative to the carbon emitted by making a journey of more than 1,700 miles in a family vehicle. The bathroom has been evaluated to be the key user of heated water in the household and it is responsible for the significant water and energy related carbon emission of around 539Kg.

The use of solar PV systems can offer about 70% hot water for an average domestic dwelling demand and space heating as well in the United Kingdom, hereby making a key difference in household energy use. Similarly, the process of heating water for bathroom activities will require a temperature between 50 to 60^{o}C in contrast to space heating needs which usually varies between 20 to 22°C. While research conducted by [22] have established that solar heating systems delivers approximately 57% of energy need to heat up cold water in the water chamber over a year period whiles saving substantial 1,850 kWh per year in fuel when compare to a gas condensing heater with high efficiency.

In the study of heat pumps, recent studies from [22] have highlighted the prospect of its environmental sustainability while emphasizing on low its carbon emissions as a factor in determining its environmental sustainability in the households, however its low energy usage is also vital reason for its efficiency. Although in USA, different authors have shown that based on the primary source of energy options, heat pumps could have different environmental effect with most negligible impact occurs in states that embraces renewable as source of power to the heat pump i.e. wind and solar. While comparing different renewable options with heat pump, [22] concluded that solar water heater integrated with heat pump is more environmentally sustainable when compared with integrating solar water heating with gas boiler with regards to of CO_2 emission.

Also, heat pumps can lose efficiency in a very cold or hot weather condition due to change in temperature and thus consuming more energy. Recent study on ASHP (air source heat pump) in the UK have shown that households without the application of heat pump emits about 11.7 tons of carbon in a year, however installing heat pump, 4.9 tons of emission was reduced in a year [23]. Considering the electric resistance heating, the working phase of the ASHP (air source heat pump) affects the environment negatively and due to the substantial amount of carbon mix of electricity presently in the United Kingdom [22,23].

V. SMART CONTROL SYSTEMS

Studies from [2] established that over 66% of energy used in heating hot water in household can be further reduced by using smart control developments. Although the consideration of building efficiency in household dwellings depends on different factors such as building physics, boiler efficiency, and operational performance of the control system. Previous studies from [28] highlighted that approximately 90% of heated hot water in a domestic setting performed inefficiently due to lack of better control systems hereby costing an additional 500 million in pounds each year. The studies further underpin the importance of using smart and suitable control devices as a necessity for high energy efficiency for domestic applications and without good control device for heating provisions, large amount of energy will be wasted and subsequently wasting costs that should otherwise be saved.

Previous work from [2] reviewed the three widely used smart control systems and are:

- on-off controller
- Proportional–Integrate–Derivative (PID) controller
- Fuzzy logic control

The above-mentioned control systems are not hard in tuning, while some are exceptional for single (input and output) systems. The on-off controller and the proportional integrate derivative controller are generally good in feedback although the proportional integrate derivative controller need information concerning the system dynamics for good performance. In a domestic building, the least problematic type of control to operate is the on-off controller which can also be called bang-bang control since its principle of operation is to switch sharply between on and off conditions. However, despite its simplicity, overshooting in a dynamic controlled state were not avoidable. The basic type of on-off controller that is normally used for residential dwellings is the ‘’ temperature control thermostat’’ [2]. In overcoming the problem of overshooting and complex dynamic or nonlinear systems, developers have preferred the use of FLC (fuzzy logic controls) systems.

VI. DISCUSSION

A bathroom that is sustainable and smart should preferably have the potential of reusing its water and energy it requires to deliver comfort, high efficiency and low running cost to its users. Different technology has now been applied to reclaim the energy needed for bathroom activities. Renewable and smart technological developments like solar water heating systems, heat exchanger, WWHR and heat pump can be integrated together to supply hot water that is extremely energy efficient for bathroom applications, this combined method will be instrumental in attaining the overall objective of carbon neutrality in the bathroom unit. Regardless of the significant function of smart and intelligent control system to achieve sustainability by saving water and energy, the smartest piece apparently is the bathroom user. The user decisively chooses its events and consumption pattern and similarly the user has a substantial influence and are the final instance for any decision regardless if ICT is employed or not. Although the function of ICT is to inform the user the effects his activities will have on environment and subsequently prompting the bathroom user in making the right decision to decrease how water and energy is used and this is what ICT is at best at as it all depends on the users to make the right decisions. However, despite the incredible effect of ICT in transitioning and prompting transition in a sustainable manner to manage the environmental resources subsequently, it faces its own distinctive unsustainability challenges as its own system and process emits more carbon than it should.

With the short comings of individual components in the bathroom, using holistic method of system interaction is important in the considerations of energy recovery, extracting environmental resources for water and energy consumption, greywater reuse in the bathroom. Even though the use of and optimizing of a single system would be good benefit however, considering the energy efficiency of a smart system is limited to the capacity of its operations as this does not really increase the sustainability of the entire bathroom. The idea of saving water and energy while employing the use of holistic method seems inevitable in improving environmental sustainability and indirectly focusing on achieving the ambitious climate neutrality goal.

The holistic method does not only jointly improve the energy efficiency and contribute to the sustainability of the bathroom but in addition can minimize size of the system and cost when contrasted with optimizing individual system in the bathroom. Also, the payback period for a combined system can be reduced to a large extent because of the government incentive for cover part of the cost for home developers and owners.

VII. CONCLUSION

Smart and sustainable bathrooms are considered as a way of achieving high efficiency in the reduction of water and energy hereby progressively moving towards protecting the environment. The system adopted in this paper is focused around achieving a highly efficient bathrooms by pursuing a balance among social, economic and environmental performance.

This paper has reviewed and laid emphasis on integrating smart technological systems with intelligent control systems to minimize the use of energy and water efficiently in a smart way that will be introduced directly from the beginning of the process to the end is important. This study have established and reviewed various technological approaches for smart and sustainable bathroom, it can be concluded that holistic approach system will jointly improve the water and energy efficiency but also furthermore it can decrease cost and size of the system components when contrasted to optimizing each separate system in the bathroom.

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