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What is the Energy Price of Independent Living? A Review of Energy Consumption of AT Products in Inclusive Smart Homes

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Abstract

Maintaining good health and independence for as long as possible is essential for a globally ageing population and people with disabilities. Assistive Technology (AT) products are intended to enhance the functional capabilities and increase independence for elderly and individuals living with disabilities. Some of AT products are relatively low-tech devices such as glasses, grips, and crutches. The application of safety-critical products that consume comparatively large amounts of domestic energy may require additional consideration in regions where reliability of energy delivery may be an issue.

A mainstream 'smart home' offers the owner the convenience of monitoring and controlling their domestic environment. These proprietary environmental controllers are now affordable through commercial systems such as monitoring and controlling environment controllers for instance Hive, Amazon Alexa, Echo and Siri etc. These systems are often low-voltage and do not appear to add significantly to domestic energy consumption. Individuals and families living with a cognitive or physical disability often require motorized systems that draw much more energy than monitoring systems. Whilst energy consumption relating to mainstream smart homes is well documented, energy use in daily activities among those with physical disability is less well defined. This leads to the question: "what is energy consumption and associated cost for independent living for the people with disabilities within a smart home?" To explore this question further, a literature review of smart home and specific high-energy requirement equipment was completed. Databases were chosen that provide a wide range of literature that has a focus on smart homes and AT products associated with tasks that aid manual handling and moving. A number of personas were created from information gathered from the literature review to provide an indication of the amount of energy consumed, with an indication of when spikes in demand may occur. The study concludes with the comparison of an AT smart home with a mainstream equivalent, savings in care costs and consequences of power outage for the AT homes. Areas for further research are also suggested.

Keywords:

Assistive Technologies, Energy Consumption, Independent Living, Smart Homes,

INTRODUCTION:

Housing design must support independent living for all people- irrespective of disability or circumstance (Dewsbury and Edge, 2001, p. 2)

The world demographic changes have accelerated population aging which has resulted in an increase of elderly population and people with disabilities (Newell, 2003; Sun, Wilson, Schreiber, & Wang, 2017). According to World Health Organization (WHO) (2011), over one billion people (10% of world population) are estimated to have some sort of disability, subsequently, the global demand for Assistive Technology (AT) products has increased (Carver *et al.*, 2015). Those demographic changes has led to a new model for elderly and people with disabilities that empower those individuals to adopt a satisfying lifestyle in the residence of their choices (Demiris and Hensel, 2008).

The Assistive Technology Act 1998 and Assistive Technology Act 2004 defines Assistive Technology as follows:

Any item, piece of equipment or product system whether acquired commercially off the shelf, modified, or customized that is used to increase, maintain or improve functional capabilities of individuals with disabilities (Scherer and Glueckauf, 2005, p. 133; Cook, 2009, p. 128; Shinohara and Wobbrock, 2011, p. 705; Cook and Polgar, 2015, p. 17).

This broader definition of AT includes devices ranging from low-tech products (i.e. glasses, grips, and crutches etc.) to safety-critical, high-tech (i.e. mobility devices, powered wheelchair, hoist, profiling bed, etc.) products that could be helpful for individuals with conditions affecting mobility and posture, their care-givers and families (Brotherson, Cook and Parette, 1996). Corresponding to the lesser complexity and cost, low-tech products are comparatively appealing for families that incorporate them in domestic settings (Cook and Polgar, 2015). Nevertheless, responding to the inability of elderly and people with disabilities, high-tech AT devices also enable them to perform their Activities of Daily Living (ADL) such as walking, climbing stairs, cooking, bathing etc. (Salah *et al.*, 2011).

Independent living persists as a critical issue not only for elderly, but also for people with disabilities, who deem to remain at their dwellings and wish to increase their Quality of Life (QOL) (Demiris and Hensel, 2008). The provision of assistive technologies and environmental improvement (Home adaptations) is an increasingly enticing approach for supporting elderly and people with disabilities to maintain independent living and to improve their QOL (Lansley, McCreddie and Tinker, 2004). AT devices up to their extent ensure independent living for their users (Salminen *et al.*, 2009), equally, smart home remain essential subject towards environment improvement and are being pursued globally, in response to technological advancement, increasing health-care cost and the desire of elderly and people with disabilities to maintain independent living at the dwellings of their choice (Demiris and Hensel, 2008).

Smart home may be thought of as a network that incorporates household items, (electronics, security, communication and assistance devices), controlled by individuals through smart home technological devices (Storey, 2011). Recent years have seen a rapid growth in the development of smart homes and is predicted to grow in future. 'Smart home' refers to a term describing the residence equipped with technology that enables monitoring and controlling for residents and/or promotes independent living and increase inhabitant's QOL (Demiris and Hensel, 2008). Furthermore, a smart home facilitates the occupants by providing sufficient access to assets, control interfaces, and technologies for improving their QOL through convenience, increased connectivity and reduced cost (Zipperer *et al.*, 2013). In daily lives, a smart home system provides devices that are not limited to home appliance control; they may also comprise of AT devices such as robotic assistance, autonomous wheelchair, stair lift etc. (Chan *et al.*, 2009). By integrating these devices, a smart home system assists the occupants in their dwellings. However, the incorporation of these technology-based devices could have added burden in overall energy consumption.

In both developing and industrialized countries, domestic energy usage accounts for a substantial amount of the total energy-consumption. The operation of various types of domestic appliance, relies on energy consumption and has been documented in relation to mainstream household appliances (Wood and Newborough, 2003). For elderly and disabled individuals, energy-consumption of AT devices remains an important element of AT product acceptance, contributing to the use or subsequent abandonment of devices (Boucher, 2018). The problem of energy deprivation in dwellings are commonly described by an expression known as 'energy poverty'. This notion has been widely discussed to address the deficient access to energy, specifically for disabled and elderly occupants, indicating their health concern (Bouzarovski and Petrova, 2015). In a domestic environment advanced mobility AT devices, such as hoists, lifts or powered wheelchairs, consume relatively more energy for their operation compared to other mainstream devices, (Boucher, 2018). Whilst energy consumption relating to mainstream smart homes is well documented, energy use in daily activities among those with physical disability is less well defined.

OBJECTIVES:

The aim of this paper is to identify the energy consumption in mobility AT devices and associated cost for independent living within smart home. Specific objectives are:

- To identify the factors impacting the energy consumption for elderly and people with disabilities
- To analyze and compare energy consumption in mobility assistive technology in smart home settings with a mainstream equivalent

Primarily the focus is on smart homes that is intended to monitor and improve health-related constraints, to whom, Rialle et al. (2004) referred as 'Health Smart Home'. The term smart homes refer to facilitates designed to energy efficiency.

SMART HOME SYSTEMS:

Over the past few centuries, technological development has influenced the notion of traditional houses which experiences considerable transformation from typical conventional home to more technology-based smart home. The reorganization of family structures, such as from diminished extended family systems to more adapted analytical concepts of family, has resulted those transitions in conventional housing system. In response to demographic ramifications of erratic family patterns, the conception of conventional family home has been transformed gradually (Dewsbury and Edge, 2001). Concurrently, demographic changes bring about new challenges for homes to cater the needs of individuals in their dwellings. For example, the rise in single occupancy homes has increased the complexity of support disabled people through an extended and remote family structure (Dewsbury and Edge, 2001). Accordingly, the design of dwellings has changed to address these societal changes. However, traditionally the home environment is considered as something that accommodates the inhabitant's needs, but, *it is often difficult to make the environment adapt to the changing needs of the occupier* (Dewsbury and Edge, 2001, p. 4). Often the individuals have varying needs, therefore, the provision of assistance needs to be tailored in accordance to each person (Chan *et al.*, 2009).

Referring to the designs of dwelling, smart homes are relatively recent development, that integrates domestic household with control feature of home environment. Primarily, smart homes were being considered as a design development for home for rich, however, with internet-based smart technological devices it is accessible for other individuals. This is often termed 'the Internet of Things'. The automation of domestic appliance with smart controls (such as mobile phones) has not been considered as an application for care sector. Conversely, assistive technologies has embraced by the care sector immediately, while the implication of AT within smart home has not been accepted significantly (Dewsbury and Edge, 2001). A mainstream 'smart home' offers the owner the convenience of monitoring and controlling their domestic environment. These proprietary

environmental controllers are now affordable through commercial systems such as Hive, Amazon Alexa, Echo and Siri from Apple.

Originally, the implication of smart technologies was applied to regulate environment systems i.e. heating and lighting etc., but the adaptation of those technologies has extended to household appliances in smart home (Dewsbury and Edge, 2001, p. 9). In homes, the smart technologies serves as same as that of AT to build an integrated environment featured with automated home and devices capable of communicating with each other (Dewsbury and Edge, 2001, p. 9).

The increase in elderly and people with disabilities has resulted demographic changes that has reformed the societal needs. The design of buildings has attempted to integrate these new pressures placed on dwellings. The design of built environment specifically for elderly and individuals with disabilities has observed some practical and theoretical transformations. The emergence of new terms universal design, barrier free design or lifetime homes are evidence of these transition. Commonly barrier free design indicates to the architecture design that meets the necessitates for accessibility and permits the widest range of individuals, for free mobility with the available facilities (Martin, 1992, p. 6; Dewsbury and Edge, 2001, p. 7). As posited by Martin (1992) *barrier free design is about making the environment a more accessible and usable place for a wider range of people with a range of disabilities* (Martin, 1992, p. 7; Dewsbury and Edge, 2001, p. 4).

The conventional approach to address the issues related to disability and rehabilitation is tended to restrict the role of AT devices in delivering different level of assistance and support to the users. The concept of barrier free/universal design principal within the domain of smart homes, often integrates generic elements of AT devices; such as ramps, automated doors, etc. into dominant design (Dewsbury and Edge, 2001, p. 7). But, the built environment, designing and employing AT solutions require the providers to uses 'client-center approach' to accurately evaluate the needs of those living with disabilities (Dewsbury and Edge, 2001; Dewsbury and Rouncefield, 2002).

In a smart home, elderly and/or individuals with disabilities are likely to face additional cost of energy (home adaptation, mobility devices etc.) to secure their health and to ensure they led improved lifestyle (George, Graham and Lennard, 2013). Hamza *et al.* (2011) argued that older individuals are growing proportion of world population and likely to face challenges relating to energy consumption by household appliances within their dwellings. On another instance, Robinson *et al.* (2017) addresses the reduced anxiety of elderly in relation to fuel poverty as well as to highlighting the concern towards accepting AT device, proposes an ICT (information and communications technology) system. Importantly, Zipperer *et al.* (2013) reported, state of the art on electricity management system within smart homes. Furthermore, various forms of electricity consumption (thermal, electric loads and smart appliance etc.) with their monitoring systems that uses low-voltage processors has been documented with focus on daily household appliances (Zipperer *et al.*, 2013). The negative health impact of added energy cost is likely to effect elderly and individuals with disabilities (George, Graham and Lennard, 2013). As mentioned previously, low-tech AT product are less complex and does not require extra energy. However, the AT devices for cognitive or physical disability often require motorized systems (high-tech AT) that draws much more energy (Boucher, 2018), impacting the overall energy consumption of smart home. Whilst, the literature review suggests the 'home-center approach' to assistive technologies provision for disabled individuals should be adapted to improve the usability of those devices within the dwellings (Brotherson, Cook and Parette, 1996). But, still does not address the energy consumption of those high-tech AT devices within smart homes. This leads to the question: what is energy consumption and associated cost for independent living for the people with disabilities within a smart home?

Pilot Study estimation of enegery in mobility AT devices:

Zipperer *et al.* (2013) document various methods to measure energy consumption at in smart homes, including smart meters, automated home energy management (AHEM), smart phone apps, etc. For the

primary research, maximum power consumption for AT devices need determined. Therefore, the author conducted a preliminary study to inspect the energy consumption of frequently used mobility AT appliance in residence and compare them against energy consumed by the mainstream household devices. This study had two goals: initially, to determine the energy utilization of AT devices, which will provide basis to calculate associated energy cost; and second, the impact of amount of energy consumed by the AT device on overall energy consumption of smart homes.

METHODOLOGY:

In domestic environment, from three major forms of disability (Physical, Sensory and Emotion), mainly physical disability causes the restricted motor function such as walking, climbing stairs, reaching, lifting etc. (Arshak, Buckley and Kaneswaran, 2006). The individual with those conditions may require mobility AT devices that comprises of range of devices including wheelchair (manual, powered), stair lifts, ceiling hoist etc., to overcome/minimize those restricted mobility activities. To measure the energy consumption and associated cost, only those high-tech AT devices were selected having frequent application in domestic environment, those of stairs lifts, wheelchair, automated doors and ceiling mounted electric hoist. For this preliminary study, the energy consumption of various mainstream household appliances was determined and compared against energy utilization of mobility assistive technology devices.

The energy consumption in operating an appliance is generally labelled by the ‘Wattage (W)’ or ‘Power rating’ for that specific device (Saidur *et al.*, 2007). Although, Wattage (W) reply on various factors such as, brand of device, types of appliances etc. But, for a given appliance of same type, for instance, Air Condition of different brand or model) operates within particular wattage limit (power range). Hence, it could be appropriate to identify the wattage limit for major type of mobility AT products that has frequent application in smart home.

For many appliances, product label shows the details of specific appliance, also, outlines the maximum energy consumption of devices in the form of Wattage (W). The amount of energy (electrical) consumed [$P_{(w)}$] by an appliance can be determined through their information such as Voltage [v] and Current [I] by utilizing following formula:

Appliance operating on Direct Current (DC)

$$P_{(w)} = V_{(v)} \times I_{(A)}$$

Appliance operating on Alternative Current (AC)

$$P_{(w)} = V_{(v)} \times I_{(A)} \times PF$$

*PF= Power Factor, which a ratio between true power and actual power ranged between (0-1)

In addition to calculate the wattage power of appliance, the energy consumption in kilowatt-hours per day was determined by using following formula:

$$E_{(kWh/day)} = P_{(W)} \times t_{(h/day)} / 1000_{(W/kW)}$$

To estimate the energy consumption (W) by the aforementioned mobility AT devices in a smart home, the related information (V & I) were obtained from related seller websites. To collect this relevant information of appliances, the product manuals having technical specifications about the products were explored. Additionally, the energy consumption (W) of mainstream domestic appliances, were gathered from wholesalesolar.com.

RESULTS:

This study included, estimation of energy consumption in four high-tech mobility assistive devices. Table (1) represents those primary assessment of energy consumption (W) by these appliances, when used for the period of one hour in a day. Among those products (wheelchair, stairlift, hoist, sliding doors), powered wheelchair found to consume largest portion of energy (W=1500/hr). Although, the energy utilization of each AT devices found not to have a major impact on the overall energy consumption of home. The possible reason is the enhanced technological development (from AC operated appliance to DC), which has impacted and improved the energy ingesting of those devices. In that way the energy cost of those AT devices remains comparable with other mainstream appliances of the house. However, the individuals using more than one of those mobility AT appliances, was noted to bear an extra cost energy for using those devices.

Activities of Daily Life (ADL)	Description, Frequency	At Product	Product Model	Energy Consumption in Watts (W)	Energy consumed per day (kwh/day)	Energy consumed per month (kWh/month)	Energy consumed per year (kWh/year)
Entrance	Provide access in the home, One (01) hour a day	Automated swing door	Model 4300	317	0.317	9.51	115.705
		Automated sliding door	Bi-Parting automatic	360	0.36	10.80	131.40
Walking	Mobility around the home, One (01) hour a day	Batteries operated powered wheelchair	-	1500/hr	1.5	45	547.5
Climbing Stairs	Increase access in different floors of home, One (01) hour a day	AC Stair Lifts	-	288	0.288	3.64	105.12
		DC Stair Lifts	-	168	0.168	5.04	61.32
Upright	Mobility in the home, One (01) hour a day	AC Electric Hoist	OT200	240	0.24	7.20	87.60
		DC Electric Hoist	OT200	120	0.12	3.60	43.80

Table 1: Estimation of Energy Consumption by Mobility Assistive Technology Appliances (Source: Appendix A)

Based on the aforementioned calculations, the total amount of energy consumed by those devices within a day was calculated and presented in table (2). From those outcomes, it can be noted that the collective impact on energy consumption of those devices remains substantial (Energy consumption = 5597.80 Watts-hours/day).

Appliance	Quantity	Watts (V x A)	Hours ON Per Day	Watts Hour per Day
Automatic Door	2	317	1	634
Powered Wheelchair	1	1500	2	3000
Stair Lifts	1	288	1.5	432
Electric Hoist	1	120	2	240
Total Watt Hours per Day				4306.00
Watts Required assuming inherent Efficiency Loss				5597.80

Table 2: Energy estimation of mobility AT devices per day, Source: (wholesalesolar.com, 2017)

Additionally, Table (3) presents the amount of energy consumed by of AT appliances against mainstream household products within a day. To measure the energy consumption estimation in a day (Whr/Day), calculation are performed based on a model called 'Load Evaluation Chat' developed by commercial merchant (wholesalesolar.com, 2017). The energy instigation of AT devices matches with the energy consumption of domestic appliances such as; Desktop computer, Ceiling fan, TV, LCD, etc.

	<i>Appliance</i>	<i>AC</i>	<i>DC</i>	<i>Qty</i>	<i>“*”</i>	<i>Wattage (V x A)</i>	<i>“*”</i>	<i>Hours per Day</i>	<i>“*”</i>	<i>Days per week</i>	<i>Divide By 7</i>	<i>“=”</i>	<i>Avg. Watt Hrs. per Day</i>
Energy Consumption by Mainstream appliances	<i>Fridge</i>	✓	×	1	x	-	x	24	x	-	-	=	1411
	<i>Microwave</i>	✓	×	1	x	1000	x	0.5	x	6	3000/7	=	428
	<i>Ceiling fan</i>	✓	×	2	x	120	x	3	x	7	5040/7	=	720
	<i>Desktop Computer</i>	✓	×	1	x	200	x	2	x	7	2800/7	=	400
	<i>TV-LCD</i>	✓	×	1	x	150	x	2	x	7	2100/7	=	300
	<i>Dehumidifier</i>	✓	×	1	x	280	x	2	x	7	3820/7	=	560
	<i>Blender</i>	✓	×	1	x	500	x	0.5	x	7	1750/7	=	250
	<i>Toaster</i>	✓	×	1	x	850	x	0.5	x	7	2975/7	=	425
	<i>Iron</i>	✓	×	1	x	1200	x	0.5	x	7	4200/7	=	600
	<i>Incandescent Light</i>	✓	×	1	x	100	x	5	x	7	3500/7	=	500
	<i>Printer</i>	✓	×	1	x	100	x	1	x	7	700/7	=	100
	<i>Smart phone charger</i>	✓	×	1	x	6	x	2	x	7	84/7	=	12
<i>Tablet Charger</i>	✓	×	1	x	8	x	2	x	7	112/7	=	16	
Energy Consumption by AT Devices	<i>Automatic Door</i>	✓	×	2	x	317	x	1	x	7	4438/7	=	634
	<i>Powered W/chair</i>	×	✓	1	x	1500	x	2	x	7	21000/7	=	3000
	<i>Stair Lifts</i>	×	✓	1	x	288	x	1.5	x	7	3024/7	=	432
	<i>Electric Hoist</i>	×	✓	2	x	120	x	2	x	7	1680/7	=	240
	<i>Other Devices</i>	×	✓	-	-	500	-	-	-	7			

Table: Estimation of Load Evaluation Chart for domestics appliances (source: (wholesalesolar.com, 2017))

It can be noted that, in-addition to mainstream household appliances, AT products increase the energy consumption by the individual in dwellings. Whilst, for preliminary study, the added load does not have a significant impact on the overall energy consumption of home. However, in a smart home with an individual using more than one AT devices was noted to consume, substantially, an extra amount of energy in their house.

CONCLUSION:

The demographic changes and technological advances has increased the health cost, that leads to the decentralization of healthcare form hospital to house. Therefore, the interaction between assistive technology devices and elderly/disabled individual, in a smart home setting to enhance the Quality of Life (QOL) is quite important. But, the needs of elderly and individuals with disabilities living in smart homes, have rarely been featured in academics or policy debates (Imrie, 2004). For instance, the amount of energy consumed by Assistive Technology (AT) appliances and their consequent impact on overall energy consumption of smart home has not been considered. This preliminary research suggests more effective recording of power consumption of AT device equipped homes is required. This may be achieved by smart meters, smart plugs/outlets and displayed through 'smart energy' apps.

The suggestion that power supplies may require a heightened level of reliability and potential increased consumption could have implications for accessible and semi-independent sheltered accommodation. This type of accommodation may be defined as having on-site staff support. Multiple flats or houses in a building complex that are considered accessible for independent living, which are equipped with these additional devices, may require more robust and reliable power access and distribution. This is an important aspect to consider within town planning, architectural design and electrical supply distribution.

APPENDIX A

Product	Power Supply	Energy Consumption	Reference
Power swing door opener:	AC	Product Information: Powered door opener Model: Model 4300 Power supply: 115 V / 50-60 Hz Ampere: 3amps Energy Consumption = amps x volts x Power factor Energy Consumption = $115 \times 3 \times 0.92 = 317 \text{ W}$	(Power Access Corporation, 2018)
Automatic Sliding Doors:	DC	Product Information: Automatic Sliding doors Model: Bi-Parting automatic sliding door Power supply: 120V/50-60Hz Ampere: 3 amps Watts: amps x volts Energy Consumption = $120 \times 3 = 360 \text{ W}$	(ensuit.com, 2017)
POWERED WHEELCHAIRS:	DC	Product information: Batteries operated wheelchairs Model: General Number of batteries: Two Power of batteries: 12 V, (24V for pair) Current: 50-75 Ah, (62.5 Average) Ah Energy Consumption: $2 \times (12 \times 62.5) = 1500 \text{ Watts/hr}$	(Powerpacks and batteries, 2017)
STAIR LIFTS:	AC	Product information: Residential ac powered stair lifts Model: General Power supply: 230 V/50-60Hz Ampere: 4 amps Power factor: 0.8 Energy Consumption: amps x volts x power factor Energy Consumption = $120 \times 3 \times 0.8 = 288 \text{ W}$	(thestairlift.com, 2017)
STAIR LIFTS:	DC	On average stair case uses two batteries of 12/7Ah. Power supply (batteries): 12V Ampere/hour: 7 Watts/hr: amps/hr x volts Watts/hr = $12 \times 7 = 84 \text{ Watts/hr}$ $84 \times 2 = 168 \text{ W/hr}$	(Universal-accessibility.com, 2018)
ELECTRIC HOIST:	AC	Product Information: Ceiling Mounted Electrical Hoist Model: OT200 240 V 1000 mA 240V 1amp Power factor: 0.89 Energy Consumption = $240 \times 1 \times 0.89 = 213.6 \text{ W}$	(Couplings, 2017)
ELECTRIC HOIST:	DC	Product Information: Ceiling Mounted Electrical Hoist Model: OT200 Two batteries of 12/5 V/Ah Power supply (batteries): 12V Ampere/hour: 5 Energy Consumption: amps/hr x volts Energy Consumption = $12 \times 5 = 60 \text{ Watts/hr}$ $60 \times 2 = 120 \text{ W/hr}$ Energy Consumption = watt-hours / hours e.g. Energy Consumption = $160/3 = 53.6 \text{ W}$	(Couplings, 2017)

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