AN EVALUATION OF SENSOR TECHNOLOGY RELIABILITY AND PLAUSIBILITY OF ITS USE IN PRIVATE CARE HOMES FOR INCONTINENCE MANAGEMENT

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Abstract

Some people with experience of dementia, who may lack the cognitive function to respond to incontinence, may need more frequent care from carers, and in some cases this can be described as the carer's 'burden'. Although there have been numerous studies that have addressed the management of incontinence in people with dementia through the approach to traditional techniques in care, the potential use of technology while acknowledged, is not yet prevalent in care homes. The application of sensor technology utilisation in the monitoring of urinary incontinence in care homes is not routinely practised due to the preference of traditional approaches to care. The findings from the questionnaire administered in the care homes was used to determine the constraints that will affect the design of a final device and inform the design process, taking into account the carer's perspective of the potential to monitor changes due the occurrence of incontinence**.** It was found that the effect of changes in sensor output with prolonged use, in terms of accuracy and reliability, could be minimised by calibration. This thesis posits that the current methods of assessing for incontinence in patients with dementia in care homes are neither uniform nor adequate and the current system cannot support a route back to continence although it may assist in management. The conclusion has the caveat that technological feasibility in this area might be less capable than the beliefs held by the care workers. The next step would be to develop a prototype and investigate the application of sensor technology for long term effects of sitting or lying with respect to humidity from sweating and incontinence.

Guide to the thesis

The relevant literature for two aspects of this research; the care home study and the sensor verification study (laboratory and field testing as well as system development) will be presented separately for clarity. The order of presentation will be as follows: Chapter 1 will be a general overview outlining the problem and aims of these studies. Then Chapter 2 and 3 will respectively deal with the issues surrounding the use of technology and care home management as well as the sensor testing methodology. Testing and application of the sensor technology will be addressed in Chapters 4 and discussed in Chapter 5. Greater detail concerning the contents of each chapter can be found in Table 1. By understanding the needs of the carers (public engagement), the design could be more appropriate and relevant based on what is requested within a care home environment (human application). Taking this into account, a product can be made to the needs of the carers rather than a creating a generic product for the market and then adapting it.

Table 1: Explaining the links between the chapters

Chapters	**Title**	**Description**	**Global Topics**
Chapter 2	Perceptions on using sensor technology to manage incontinence in dementia.	The study of the management of incontinence in dementia residents in care homes. Presents the findings of the telephone and questionnaire survey to determine the extent of the relationship between the engagements of technology with management	Public engagement
Chapter 3	Performance verification of humidity sensors traceable to National standards.	Addresses sensor technology testing in a variety of environments including laboratory and non-laboratory. Uses regular re=calibration in an environmental chamber traceable to National standards to verify output reliability and accuracy.	Sensor verification
Chapter 4	Application of the sensors in a simulation of care home sitting activity.	Explores the sensor detection technology exposure to human sitting to study the microclimate between the skin and the sitting interface	Human application
Chapter 5	Synopsis of results, general thesis discussion and conclusions.	Presents a general discussion followed by a short review of the related work on a basic prototype using the design ideas of the carers and the research results in order to supplement the findings	Plausibility of a humidity detection system (prototype)

Background of author

From a very young age I have been enthralled by engineering and medicine. The amalgamation of these subjects (the plethora of pure physics and engineering theories interlaced with medicine) are paramount for shaping medical advancements; I feel honoured to have contributed to this through my research. I was born in Malaysia although I lived in Cardiff between 1984 and 1986. In Malaysia I attended school until 1996 after which I returned to Cardiff with my family thus spending my final high school years gaining my GCSE's and A-levels in the mathematical sciences. I read Medical Engineering as my first degree (**BEng. Medical Engineering)** and this involved the following: development of fundamental knowledge in medical applications to support the human body; designed a stable drill end part for securing metal plate implants to bone fractures and biomechanical analysis of shaken baby syndrome using motion analysis to analyse forces involved when rice bags (simulation of baby mass) were thrown on to a calibrated laboratory surface. I then took a masters in Clinical Engineering (**MSc. Clinical Engineering)** and this involved the following: designed a powered wheelchair simulator; an existing powered wheelchair motor was fitted on a wooden platform so that any manual wheelchair could be mounted on. This was clinically used to assess the suitability of individuals in using a powered wheelchair. Driving efficiency was tested in a short obstacle course and analysed using motion analysis. At the Medical Physics and Rehabilitation Engineering unit I acquired clinical and practical skills in the following areas: Clinical assessment of people with special seating needs; use of pressure map technology to determine seat surface pressures; use of technology to promote independence; use of electrical stimulation. I then pursued a Ph.D. student post that allowed me to encompass the amalgamation of my two interest fields: healthcare and engineering: The use of detection technology to measure physiological changes at the interface between the human body and seat surface to fathom its usefulness in the healthcare setting. The quantitative (empirical, in vivo and long term periodic calibration of technology) and qualitative (public engagement) research experience gained has allowed me to acquire the ability to appreciate and conduct a broad scope of research. I initially started my research concentrating on sensor verification and the design of a prototype for detecting incontinence. In literature and the commercial market there are many incontinence detection products and techniques, however they were at a trial stage, required further research or not utilised by users. I was determined to understand what the users would require in order for such a system to be successful especially in people with dementia who may have challenges with communication. In order to attain this understanding I decided to visit a care home.

Inspiration for this study

I visited a care home in England to understand incontinence management in people with dementia and how technology could be used in line with this. This home is a dementia care centre for the elderly with fifty one beds providing short stay rehabilitation (respite) and nursing care. I interviewed a carer (team leader) from the respite centre who gave me valuable information into incontinence management. The main management for incontinence is based on routine 1 – 2 hour checking, changing of pads and regular toileting. Due to the cognitive decline of the individuals, the carers take extra care to ensure the residents are managed well in their daily lives. People with dementia usually have varying degrees of continence but are usually managed individually by the carers. The Team Leader mentioned that it can sometimes be difficult with toileting as they cannot force someone to go to the toilet or leave them until they micturate. She felt this could be seen as 'abuse and neglect' so the carers have to work extra hard to ensure that residents are encouraged to go when they needed. Carer have an NVQ level qualification which looks briefly into incontinence care (taught to recognise incontinence). Incontinence awareness is also briefed at the induction training at the beginning of a job. Statutory training carried out once a year includes 'Risk Assessment and Health and Safety' but does not go into pressure care or incontinence. Rooms in the centre is equipped with a call system. This system can connect to other technology including various switching or sensor devices such as pressure mats, bed sensors, and fall sensors. The team leader mentioned that detection sensors could work at night as it can be disturbing for residents to be changed then. Incontinence detection devices have not been used because the home relies on traditional checking methods. She was concerned that a system would create too much dependency and retract from traditional methods of checking especially in the day time. It appeared that the lack of communication between the carer and dementia person may create varying levels of care. Bridging the gap of communication would be ideal for comfortable caring relationships. Carers may not widely accept change if they are trained in a specific way. Educating carers on a wider scope of care (including the use of detection technology) would not only broaden their perspectives, it would also make them aware of their own needs whilst maintaining dignity of a person with dementia. Adapting technology with current management protocols may enable carers to understand its impact. Addressing the needs of the carers may effectively determine an ideal and accepted system. This provided the inspiration for the two way scope of my research: public engagement and sensor verification.

Acknowledgements

First and foremost, I wish to express my profound gratitude and deep appreciation to my supervisor, Professor Peter W. McCarthy for his endless guidance, invaluable suggestions and criticism as well as patience throughout my period of study. Special thanks go to Dr. Ralf Patz my second supervisor, for his support and encouragement throughout my research. I am grateful for his kind help during the development of this work. I am grateful for the additional supervision provided by Dr. Andrew Heusch (Clinical Technology and Diagnostics Research Unit, University of South Wales) who has supported me throughout my research by providing continuous encouragement and exemplary guidance. Thank you to Dr. C. Shaw (Reader in Nursing Research, Department of Care Sciences, and University of South Wales) for very kindly providing useful comments, guidance and engagement through the learning process of this thesis. Thank you to all the members of staff from the Welsh Institute of Chiropractic and the Clinical Technology and Diagnostics Research Unit, who gave their full support and encouragement throughout my studies. I would also like to thank the following people: Mrs. Lee McCarthy (Clinical Technology and Diagnostics Research Unit) for her continuous support and encouragement, Dr. F. Rinaldi (Evolution IS, Glasgow) for providing very positive guidance, Mr. Pankaj Patel for providing specialist advice on medical technology and innovation and Mr. Isak Enskog (MSc. International Public Policy, King's College London) for kindly taking the time to translate two Swedish research documents. Further thanks to the following people from the Faculty of Advanced Technology, University of South Wales: Mr. P. Stevenson (Principal Researcher) and his team, Dr. Stuart Watson, Dr. Paul Jarvis and Dr. John Wyburn. I would like to express my gratitude to my wonderful parents Dr. Rawindaran Nair and Dr. Sheladevi Nair for their abiding love and unfailing support throughout my studies. Thank you to my family (Nisha Nair, Suraj Nair and Jaden Rohan) who have been a continuous source of support and inspiration during this period of training. I could not have progressed without your unconditional love and painstaking proofreading efforts! My sincere thanks and love go out to my husband Dr. Rajesh Kumar Chelliah (Nair!) for being by my side throughout this process; I could not have done it without you. Your continuous love and support helped me to keep things in perspective which really gave me the strength to progress. Last but not least I wish to extend my appreciation to my close friends and family (my mother-in-law Mrs. Chandra Chelliah, my brothers and sisters-in-law and my lovely nieces: Maelo, Kirsty and Melissa) who supported me, gave me cheer, and helped me see the light at the end of the tunnel!

Dedication

I wish to dedicate this work to my parents Rawi and Sheila

Nisha, Suraj and Jaden Rohan

And to my gorgeous husband Rajesh Kumar.

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"Every time the mind gets 'disturbed' it loses
its stamina. But as it gains in poise and equilibrium,
it is progressing towards serenity – Shanti"
The Bhagavad Gita: Chapter 16, p. 782

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Chapter 1

Introduction to the study

"You can free yourself from aging by reinterpreting your body and by grasping the link between belief and biology" - Deepak Chopra

1.1 Introduction to incontinence and dementia

Dementia, is a neurological condition affecting the ageing population, which can cause a profound effect on daily lives (loss of personality and planning skills) among other things impacting on the person's ability to remain continent (Brown and Hillam, 2004; Getliffe and Dolman, 2007). Commonly, people with dementia do not seek treatment for incontinence as it is not viewed as a legitimate medical condition; rather it is considered a normal part of ageing (Brittain and Shaw, 2007; Price, 2007). With the progression of dementia people may feel vulnerable resulting on their becoming increasingly reliant on other people. Incontinence has often been cited as the "final straw" that influences whether a person can be managed at home or admitted to institutional care including care homes (Thom, 1997; McCliment, 2002; Thomas et al., 2004; Buckley, 2006). Urinary incontinence (UI) refers to the complaint of involuntary leakage of urine (Abrams et al., 2005; Abrams et al 2009) and is often accompanied with dementia due to the condition being a progressive decline in neurological control and awareness affecting the human body (Brown and Hillam, 2004). Apart from dementia, incontinence can be due to a number of factors such as stress, variety of neurological factors or compromise and age related conditions (Merkelj et al, 2001; Wai et al, 2010).

People with dementia invariably have natural differences such as low activity and varying diagnosis. Most ageing residents in care homes spend large amounts of time sitting during the day time (CQC, 2012). Due to this the elderly population who although are able to walk, have seating issues. The cause of their prolonged sitting period may be caused by their associated pathologies of osteoarthritis, stroke, and rheumatoid arthritis, dementia or through simply being frail (Bardsley 1984). Prolonged sitting leads to the increased potential for skin maceration because of humidity build up (Nicholson et al, 1999; Ferguson-Pell, 1992; Learning, 2003) and increased friction between the person and seat or support surface (Posada-Moreno et 2011; Reger et al., 2001; Goossens, 2006; Barnett and Arblarde, 1995; Kokate et al., 1995; Peterson and Adkins, 1982); consequently skin damage is more likely. It can also increase risk of infection entering the body placing demands on the body's defence mechanism. People with dementia who spend large amounts of time sitting, should be monitored to ensure that skin tissue remains healthy at the seat interface. The presence of incontinence would pose an additional risk to the skin. Carers are trained to offer maximum support to ensure that people with dementia feel secure and safe; however, incontinence care has been reported to be variable reportedly due to behavioural differences. A health outcome report suggested that 30% of people living in residential care homes were incontinent rising to 60% in nursing homes (National Centre for Health Outcome Development, 2000). The contributions to skin ulcer formation identified in care homes include, variations of treatment, number of staff and quality of education (Department of Health, 2000). Although routine checks and toileting regimes exist, urinary accidents are sometimes undetected or only resolved at the next check. Carers are trained to accommodate the foibles of people with dementia and although they pursue their work as carefully as they can, it has been reported to be challenging. This has often been translated into a feeling of burden in the care worker. This suggests that continence may not be encouraged causing indiscriminate use of pads, catheterisation and unnecessary referrals to expensive services (Royal College of Physicians, 1995). Better understanding of technology and products to improve lifestyle might prevent the over use of pads and encourage the promotion of continence (Wai et al, 2010; Getliffe and Dolman, 2007). Comprehensive support and care including emotional support, assistance with daily caring, incentives, regular respite, peer support and any other support outside the traditional definition of care will only enhance and motivate the carer to continue care to the highest standard.

Urinary Incontinence is part of the issue that is faced in all health related services (NHS choices, 2014; CG40 NICE Guidelines, 2006) although unfortunately a high level of cost is related to the care of those people with dementia. There are five million people in the UK who have UI and this costs the UK economy £420 million annually (Getliffe and Dolman 2007). It is estimated that there are 821,884 people who have dementia (Alzheimer's Society, 2013) and about 80-90% of this population have UI and, or faecal incontinence (Price, 2011). The annual cost of a dementia patient to the economy is £30,000 although it has been reported that general long term institutional social care and informal care of dementia patients costs the UK economy £23 billion annually (Luengo-Fernandez and Alastair Gray, 2010). When compared to other major diseases dementia costs the UK economy twice as much as cancer, three times as much as heart disease and four times as much as stroke (Luengo-Fernandez and Alastair Gray, 2010). Even with these staggering statistics, there is still lack of research into the management of incontinence in people with dementia, something that needs to be resolved to improve their well-being (Price, 2011); especially when prolonged sitting makes up a major part of their lives when residing in care homes (Care Quality Commission, 2012). Ageing well may be attributed to the advances of medicine, technology and education. Although it may be widely accepted that ageing comes with many health related conditions, an informed approach to care or self-care may be important in protecting the body from any adverse and avoidable effects of the ageing process. Technology can now be used to help increase self-awareness by recognising risks early, ameliorating or even preventing age related damage (prediction of falls or incontinence) and initiate appropriate rehabilitation. Embracing technology could facilitate and maintain independent living at any stage of life. In the early stages, people with dementia are aware that their condition is progressive. They understand that they will eventually face challenges including decrease independence when carrying out daily activities, a reduced ease in using technology and transport, maintaining social contact, hobbies and accessing services. Therefore it is imperative (at the early stages) that carers and people with dementia work together to embrace suitable support in order to enable the best quality of care. It is important for people with dementia to feel confident and positive about ageing (Price, 2011).

1.1.1 Factors which can increase risk of skin damage and infection

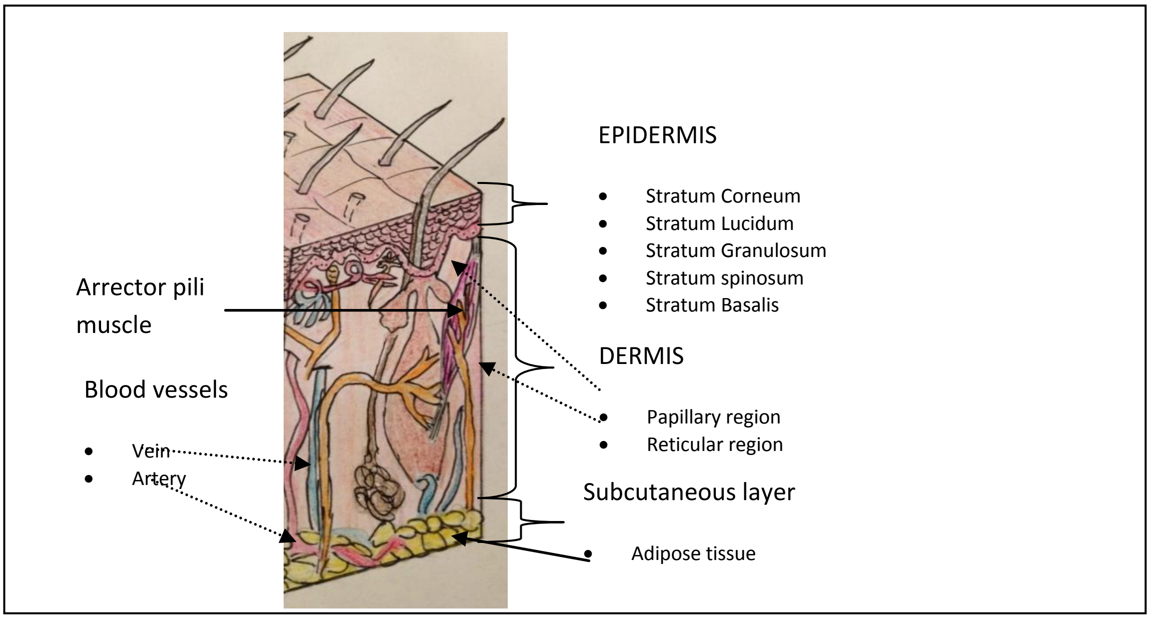
The skin is the exposed part in sitting and is the largest organ in the human body (Drake, Vogl and Mitchell, 2010). This critical protective barrier which maintains balance within the body is indispensable for human life. A complication for people with limited mobility is the occurrence of pressure sores. This can result from the exposure of skin to prolonged pressure (due to sitting or lying) which may compromise blood flow; preventing delivery of essential nutrients such as oxygen to the skin tissue (NICE, 2014) which causes tissue hypoxia (Cooper, 1998). Tissue hypoxia happens when there is inadequate utilisation of oxygen (cellular metabolism) due to the occlusion of blood flow which could decrease the partial pressure of oxygen (pO2) in a given tissue (Semenza, 2000). The decrease in oxygen delivery to a tissue could cause metabolic acidosis which is developed in the hypoxic tissue itself (Sabatini and Kutzman, 2009). Metabolic acidosis is the fall in concentration of blood bicarbonate (responsible for decreasing the pH of the blood) and is the process that leads to the fall in blood pH or acidemia (Robergs, Ghiasvand and Parker, 2004; Faadiel-Essop, 2007).

Since the rate of metabolic activity is affected by the blood fluid pH, the low state of blood pH (acidaemia) means that the blood is too acidic and this may cause life-threatening conditions (Jung et al, 2011). The normal pH of blood is 7.4 and the increases of blood acidity has been found to raise the chances of developing inflammations in the body as well as an array diseases such as cancer, osteoporosis, arthritis, diabetes, cardiovascular diseases, Crohn's disease, kidney disease and psychological dysfunction (Misbin, 2004). Chronic exposure of healthy tissue to an acid environment produces toxicity resulting in cell death (Gatenby and Gawlinski, 2006). During sitting, prolonged pressure in the same position for extended periods of time can also cause the compression of the venous system resulting in pressurisation of the capillaries and formation of more interstitial fluid (lymph) (Vlaovic, Domljan and Grbac, 2012; Hampton and Collins, 2004). This causes increasing resistance to blood flow through the area and slows down blood movement, thus compromising nutrient supply and waste product removal (Hampton and Collins, 2004). The weight or pressure of a body on surfaces whilst sitting or lying can cause great risk as the body weight is concentrated on a small area of tissue which may happen when patients are moved in their beds in hospitals or care homes (Ham, Aldersea and Porter, 1998; Bader et al., 2005). Tissue closer to the bone can undergo greater pressure compared to surface tissue due to compression against the hard surface of the bone (Ham, Aldersea and Porter, 1998). There are two types of damage that can occur when moving a person: shear and friction damage. Shear damage occurs when attempts to move the body along a surface (only moves the layers of tissue and not the body) cause the tissue underneath the surface to be distorted and damaged (Cooper, 1998). Friction damage occurs when the body is successfully moved along a surface and an abrasive action damages the skin surface with the shear damage that has already occurred underneath the skin (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004). There are factors other than pressure that can reduce tissue viability. The impairment of delivery for essential nutrients to the skin tissue can be exacerbated by increases in temperature or humidity (Tagami, 2010). This will result in sweating and the accumulation of moisture on skin (even from incontinence) causing it to become thinner and more easily damaged, slows the healing process and make infection more likely. There is a complex interaction between the environment, human body and the properties of the surface material of seats such as wheelchair cushions and mattress (Cooper, 1998). At this interface a microclimate is generated that can affect the tissue physiology (Nicholson, 1999). Aspects of this include heat trapping caused by lying and sitting on support surfaces, which is thought to increase the metabolic rate (Nicholson, 1999; Ferguson-Pell et al, 2009). Increases in skin temperature, in turn increases skin moisture from sweating both which can contribute to ulcer formation (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004). Moisture from sweat and UI may cause skin maceration which in turn could weaken damaged skin (Ersser et al., 2005). Already damaged skin could be more susceptible to poor healing and infection under this condition (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004). The elderly population and disabled individuals (less able to relieve pressure) who experience long periods of immobility and loss of sensation are prone to developing pressure sores (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004; Getliffe and Dolman, 2007). Normally a person would, via their nervous system, receive and react to information from the area of skin at risk; however, this may not be possible in those such as the elderly with limited mobility or impaired nervous systems as in the case of elderly people with dementia (Wai et al., 2010). The elderly with diabetes and others with neurological compromise might increase the risk of damage to parts of the skin because of poor feedback (Wai et al., 2008). Although there appears to have been limited critical discussion of the inter-relationship between urinary incontinence, the vulnerability of the skin and the clinical implications (Ersser et al., 2005), pressure sores can result from a mixture of external damage (extrinsic factors) and decreased tissue viability (intrinsic factors).

1.1.2 Complexity of skin as a tissue: structure

It is the skin that is directly interfaced with the support surface in the sitting position (MacGregor, 2010). The skin is comprised of structural materials such as collagen (a group of proteins found in connective tissue), elastin (protein rich in hydrophobic amino acids such as glycine and proline) and reticulin (a type of collagen containing carbohydrates) fibres in an amalgamation of substances which is essential for the survival of the cells living in it (Tagami, 2010; Bader et al 2005; Wildnauer, Bothwell and Douglass, 1971). The skin is the largest organ in the body and its average surface area in an adult is between 1.5 to 2m^2 and weighing around 2.7 kg (making up to 16% of the average body weight) (Bader et al, 2005; Drake, Vogl and Mitchell, 2010). The skin protects the internal hydrated tissues and organs from being desiccated in the external environment as well as protects against external injuries, attack of microorganism or viruses, contain somatic sensory nerve endings (of pain, temperature and touch) and regulates body temperature (Tagami, 2010). The human skin consists of three main layers (Figure 1.1) the epidermis, dermis and the subcutaneous layer (adipose tissue) (Tagami, 1980; Tagami, 2010; Drake, Vogl and Mitchell, 2010). Deeper tissues include muscles, tendons, ligaments, joint capsules and bone all of which lie beneath the subcutaneous layer (Drake, Vogl and Mitchell, 2010).

Figure 1.1: Integumentary system (adapted by author from Drake, Vogl and Mitchell, 2010)



Key: The epidermis has five strata or layers and they are as follows (Hampton and Collins; Drake, Vogl and Mitchell, 2010):

- **Stratum corneum (SC): Top most layer of containing the dead squamous epithelial cells**
- **Stratum lucidum: Friction reducing second layer found in palms of hands and soles of feet.**
- **Stratum granulosum: The intermediate layer where cells lose their nucleus (cytoplasm)**
- **Stratum spinosum: This is the second last layer, and the thickest layer of the epidermis.**
- **Stratum basalis (SB): Or germinative layer is a single celled layer containing three types of cells:**
    1. **Melanocytes: Cells that produce melanin giving skin its pigmentation and photo protection.**
    2. **Merkel cells and Merkel disks: Creates synaptic contact with somatosensory afferents. They are associated with the sense of light touch used for discrimination of shapes and textures.**
    3. **Langerhan cells: Cells involved in the immune system.**

The skin with all its layers is around 1 mm thick and cells in the skin called keratinocytes produce kerotenes which are proteins that help give our skin strength and resistance to environmental toxins and physical stress (Greaves, 1976; Xu and Lu, 2011; Drake, Vogl and Mitchell, 2010; Hampton and Collins, 2004; Bader et al., 2005). The epidermis of the skin has an impermeable and avascular superficial layer of dead keratinised stratified squamous epithelium which is very difficult for microorganisms on their own to penetrate into from the outside and water loss from the inside is carefully controlled (Hampton and Collins, 2004). The stratum corneum (SC) which is the top most proteinaceous layer of the epidermis consists of 20 tightly stacked layers of epidermal cells which together are about 20 µm thick. The SC effectively creates a barrier from microbes and chemical substances and allows water loss in the range of between 0.2 and 0.5 mg.h / cm^2, and it is this incredible property that allows humans to live even in the driest of environmental conditions (Sekiguchi et al, 2001) and protects the internal body from desiccation (Tagami, 2010). The SC is flexible if it contains more than 10% water although any less (or dehydration) would result in the SC becoming hard and brittle (Sekiguchi et al, 2001). There are no blood vessels or large encapsulated nerve endings in this layer, and squamous cells in the SC are rubbed off and replaced by cells from the germinative layer or SB (last layer of the epidermis that interfaces with the dermis, as a ridged structure of cells called the papillae which generates cells and aids nutrition) (Hampton and Collins, 2004; Wildnauer, Bothwell and Douglass, 1971). As cells progress upwards to the top surface from the germinative layer they lose the nutrition and therefore become dead cells, with no cytoplasm. Complete replacement occurs within 40 days (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004). The combination of lipids and proteins enables the dead skin cells to maintain their barrier to water loss (Tagami, 2010). Collagen is a type of fibrous protein which makes up 30% of the human body and contains the specific amino acids: glycine, proline, hydroxyproline and arginine (Drake, Vogl and Mitchell, 2010; Hampton and Collins, 2004).

Collagen is made in the dermis and is the main component of connective tissue. It supports and connects the organs and tissues in the body and there are 25 different types. It protects the skin by preventing absorption and the spread of pathogens, environmental toxins and microorganisms (Drake, Vogl and Mitchell, 2010; Hampton and Collins, 2004). It also helps with its firmness, suppleness and constant renewal of skin cells. Collagen fibres have incredible tensile strength which is important for the cell structure (Bouten, 1996). Collagen works with keratin to provide the skin with its strength, flexibility and resilience (Drake, Vogl and Mitchell, 2010; Hampton and Collins, 2004). Ageing causes the reduction of collagen formation resulting in the weakness of cell structures and skin becoming thinner being damaged more easily, resulting in its sagging and wrinkling. Tendons and ligaments become more fibrous and the joints get stiff (Drake, Vogl and Mitchell, 2010). Elastin works hand in hand with collagen by providing tissue flexibility and together are present in 70% of the dermis (Hampton and Collins, 2004; Drake, Vogl and Mitchell, 2010; Bouten, 1996). Elastin fibres are proteins found in connective tissues and are comprised of protein fibrillin and elastin (Hampton and Collins, 2004). The small blood vessels in the skin provide nourishment to maintain cell growth (Drake, Vogl and Mitchell, 2010), Glycine and Proline are hydrophobic rich amino acids . Ageing and poor nutrition causes elastin production to slow down and the degeneration of these fibres can lead to the loss of skin hydration (Drake, Vogl and Mitchell, 2010; Tagami, 2010; Clarys, Barel and Gabard, 1999). Proteins attract water which helps in the balance of body hydration. The proteins in bloods usually attract water from the tissue spaces back into capillaries. If the capillary walls are hyper-permeable then the protein may leak out of the blood and go back into the tissue spaces (Drake, Vogl and Mitchell, 2010).

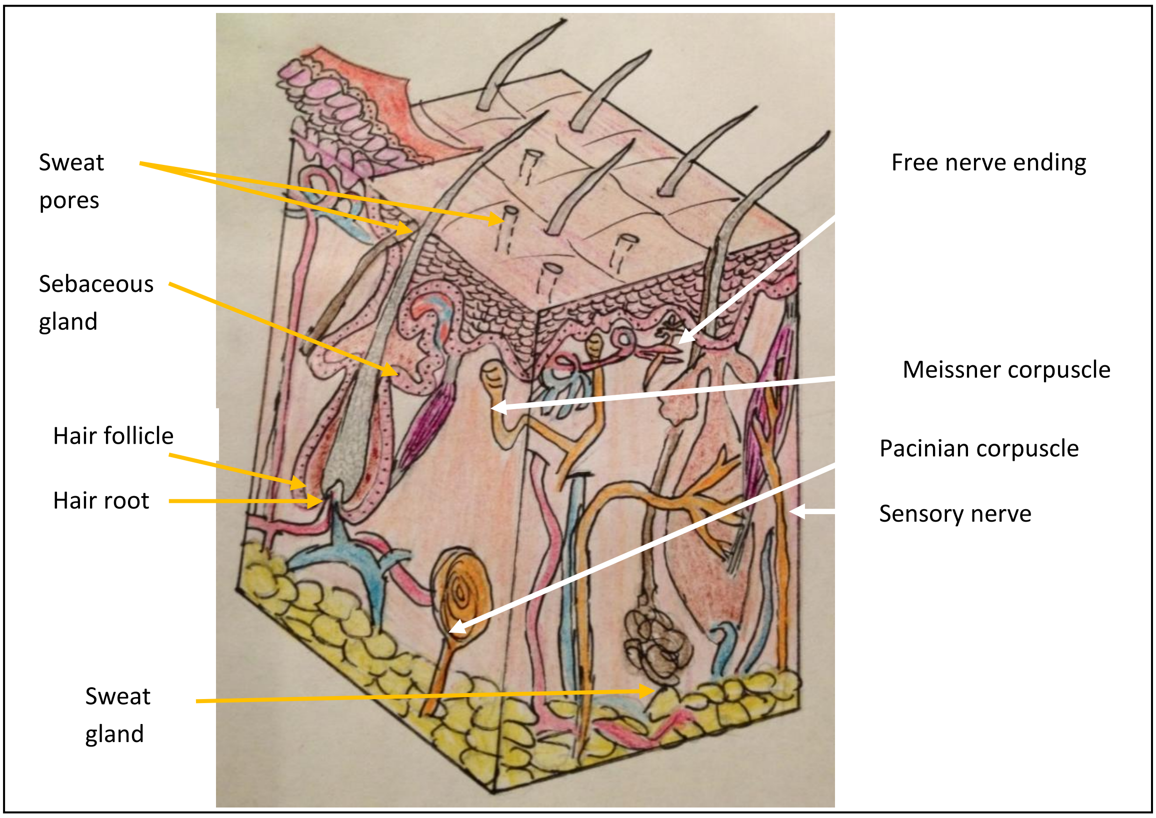
1.1.2i Hydration of the skin

In young skin there are plenty of water holding substances such as amino acids and keratin cells, lactate from sweat and intercellular lipids as well as glycerol which can bind water in the skin surface (stratum corneum or SC) (Drake, Vogl and Mitchell, 2010). The water content of living tissue in the elderly is high, although dry skin reflects a decrease in water content in the superficial part of the SC in the epidermis (Tagami, 2010). Maintaining skin hydration in the elderly is imminent in order to avoid complications (Tagami, 2010). An in vitro experiment carried out 60 years ago, found that SC fragments became hard and brittle when dehydrated, and did not recover when topical emollients such as petroleum jelly or olive oil were applied (Blank, 1952). However upon absorption of water the SC became soft and flexible, improving the mechanical properties of the skin (Tagami, 2010). When the skin ages, these water-binding substances in the superficial part of the SC become weak. In addition to this, the well hydrated living tissues in the dermis may provide a poor supply of water to the SC because of the decrease in SC cell layers in the elderly may reduce the pathway for water to travel through. Therefore the development of dry skin appears to be due to the reduced water supply from the underlying epidermis as well as poor water holding capacity of the SC causing it to be less effective in binding water (Hampton and Collins, 2004;Tagami, 2010).

1.1.2 ii Blood and lymphatic vessels

The arterioles and veins (Figure 1.2) make up fine networks with the capillary branches which supply the skin (Hampton and Collins, 2004). The living cells depend on a regular supply of oxygen (O_2) and nutrients from the blood vessels of the circulatory system and the removal of waste and toxins through the lymph vessels of the lymphatic system (Drake, Vogl and Mitchell, 2010). O_2 is diffused from the blood into the cells at the arteriole end of the capillary bed at a hydrostatic pressure of 35mmHg (5kPa). The osmotic pressure in the capillaries is about 25mmHg (3kPa) (Drake, Vogl and Mitchell, 2010). CO_2 is removed from the cells and into the blood at the venous end of the capillary bed at a hydrostatic pressure of 15mmHg (2kPa) and osmotic pressure is 25mmHg (3kPa) (Ferguson-Pell *et al.,* 2009). The blood vessels and lymph vessels in the skin have non-rigid wall structures and therefore when the pressure outside the vessels exceeds the pressure inside the vessels, they will collapse (Hampton and Collins, 2004). A variety of sitting pressures have been found to contribute to the total depletion of O_2 (anoxia) (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004). It was originally argued that normal capillary pressures at the sitting interface ranged from pressures of 32 mmHg at the arteriole end, to less than 12 mmHg on the venous end, although 12 mmHg is enough for capillary closure and is generally the indication for tissue damage (Landis, 1930). These pressures in a short duration of sitting are relieved by reperfusion of blood flow to the occluded area following re-establishment of the blood supply (reactive hyperaemia) (Hampton and Collins, 2004). However variations in the intensity of pressure required have been found in the elderly and younger individuals. For example in elderly subjects it has been considered that anoxia may occur at occlusion pressures as low as 40mmHg (Bader and Gant, 1988), whereas complete depletion of O_2 in tissues of younger subjects was only found when pressures as high as 540 mmHg were applied (Seiler and Stahelin, 1979). Predominantly the occurrence of anoxia, especially over the bony prominences under pressure, was found when pressures in region of 30 - 150 mmHg was applied (Bar 1989). It was also suggested that an exposure time of 2 hours to an external pressure of 70 mmHg may cause ischaemic lesions in all tissues (Dinsdale, 1974). The collapse of these vessels will prevent or stop any fluid flow through them (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004). Under such pressures the lymph vessels will be unable to remove waste (as they too will be occluded) and therefore a build-up of toxins may occur if the occlusion persists (Ham, Aldersea and Porter, 1998).

Figure 1.2: Components of the integumentary system (adapted by author based on Drake, Vogl and Mitchell, 2010)



Key: The skin has an impermeable and avascular top layer that is impossible for microorganisms to penetrate from the outside and water loss from the inside is carefully controlled (Hampton and Collin, 2004). It contains exocrine glands which play a prominent role in regulating temperature and protecting against the ultraviolet light. The deeper subcutaneous layers which contain nerves, glands, adipose tissue, muscular tissue and fibrous and elastic connective tissues play an important role contributing to homeostasis (Hampton and Collin, 2004; Bader et al., 2005).The epidermal surface has replete amounts of hair which plays a prominent role in regulating temperature and protecting against the ultraviolet light (Bader et al 2005; Wildnauer, Bothwell and Douglass, 1971). The epidermis which has no blood supply gets its oxygen and nutrients from the interstitial fluid derived from blood vessels in the papillae of the dermis (Wildnauer, Bothwell and Douglass, 1971; Bouten, 1996).The dermis consists of two layers, a papillary and elastic layer. Both of these layers contain three types of tissue; collagen (strengthens and holds tissue together) interlaced with elastic tissue as well as reticular fibres (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004). Fibrous and elastic connective tissues support this layer as each structure plays an important role contributing to homeostasis (Hampton and Collins, 2004). The rupture of the elastic fibres happen when the skin is over stretched and this causes permanent striae (stretch marks) (Ham, Aldersea and Porter, 1998). Collagen fibres have water-binding properties which give the skin its tensile strength however this declines with age (Tagami, 2010). The main cells found in the dermis are fibroblasts, macrophages and mast cells. The dermis contains the hair follicles and root, the hair muscle (arrector pili), the superficial sensory nerve (Meissners corpuscle) and deep sensor nerve (Pacinian corpuscle), the sebaceous glands, sweat glands, blood vessels, lymph network and the subcutaneous adipose tissue and muscle layer (Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004).

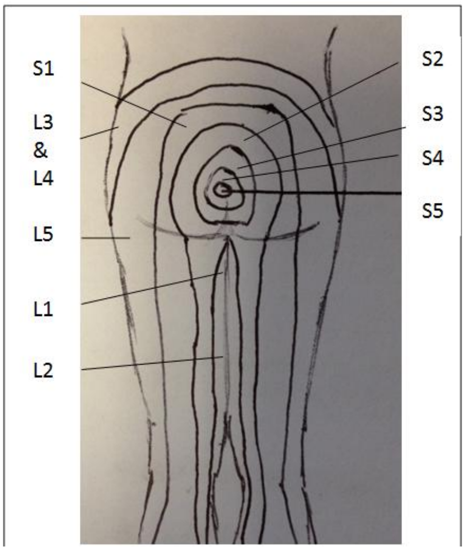
1.1.2 iii Nerve control

Touch is a pressure stimulus which is applied to the skin. Pressure is best detected when the skin changes its shape, such as in sitting when the buttock area and thighs get in contact with a sitting surface (Geldard, 1972). Pressure that is applied constantly to the skin such as when in sitting is adapted to by the human somatosensory system. Although the type of pressure and size of the stimulus affects the time it takes to adapt which can usually be fast. Moving stimulus by changing movement during sitting after prolonged periods of time allows for the restoration of sensitivity (Dinsdale, 1974). The spinal cord is placed within the bony spinal column and the somatosensory system is organised within this structure. Along the spinal cord, a pair of spinal nerves leaves on each side at each vertebra they are numbered according to the location of their exit from the spinal column (Drake, Vogl and Mitchell, 2010). The nerves at the top of the vertebrae of the spinal column are called the cervical and there are eight of them. The next group come from the thoracic region and there are twelve vertebrae's. Below this it is the lumber (5) and the sacral (5) region that generate the spinal nerves. Each spinal nerve collects information from a designated area of skin called dermatomes (Figure 1.3). These receptors send signals up to the spinal cord and to the brain (Drake, Vogl and Mitchell, 2010). Body temperature is carefully controlled between the skin thermoreceptors and the hypothalamus (main control centre in the brain). The temperature regulating centre in the brain is sited in the hypothalamus which is responsive to the temperature of circulating blood. The hypothalamus is able to control body temperature though autonomic nerve stimulation of the sweat glands. The vasomotor centre in the medulla oblongata controls the diameter of the arterioles and capillaries and in turn controlling the amount of blood circulating in the dermis. So therefore when the body temperature rises, vasodilation of the blood vessels occur, and a decreases in body temperature causes vasoconstriction (Drake, Vogl and Mitchell, 2010).

1.1.2 iv Sweat glands

Sweat glands are stimulated by sympathetic nerves and respond to raised body temperature and fear. Body core temperature is 36.8 °C or 98.4 °F and an increase from 0.25 °C to 0.5 °C stimulates the sweat glands to produce sweat which travels to the skin surface via ducts (Drake, Vogl and Mitchell, 2010). Water is then evaporated from the skin surface to cool the body. In high temperatures and relative humidity's sweat droplets form on the skin because the rate of sweat exceeds the rate of evaporation (Drake, Vogl and Mitchell, 2010). However at low temperatures and relative humidity, heat loss due to evaporation and expired air happens unnoticeably. This is referred to as insensible water loss (500 ml a day) and sensible heat loss.

Figure 1.3: Dermatomes on the sitting area (Adapted from Drake, Vogl and Mitchell, 2010).



Key: The nerves supplying the skin in the sitting area come from L1- L5 (L for lumbar) and S1-S5 (S for sacral) regions of the spinal cord. The skin contains specialised nerve cells located deep in the dermis (Pacinian corpuscle and Ruffini corpuscle) as well as superficially (Meissner's corpuscle, Merkel disks and Krause's end bulb). There are also free nerve endings distributed in the layer. It is these cells that enable the skin to feel pressure, pain, touch and temperature. It is difficult to pair the particular sensory experience with the receptor types, however the receptors may be classified into three categories; Mechanoreceptors (responds to deformation of the skin surface i.e. Pacinian Corpuscle and Meissner Corpuscles), Thermoreceptors (where the skin responds to warm or cold stimuli based on the location of the receptors) and Nociceptors (receptors that respond to potential damaging stimuli; free nerve endings may act as pain receptors).

Sensible heat loss also known as dry heat loss is the heat lost through conduction (touching surfaces), convection and radiation (Chen, 2010). Insensible heat loss or wet heat loss, on the other hand is due to diffusion and evaporation of moisture through skin and from the respiritory tract (Nicholson et al ,1999). In a resting individual, the total heat loss from a body surface of 1.8 m² is 64 W/m² and the moisture vapour flow (transpiration rate) through the skin per day is 0.40 kg/m² (average) (Nicholson et al, 1999; Ferguson-Pell,*et al.,* 2009; Drake, Vogl and Mitchell, 2010). Excessive sweating (hyperhydrosis) from the body causes increased susceptibility to infection as well as dehydration and chronic depletion of sodium chloride, unless they are replenished. If the human body is in an environment that has a high temperature the amount of salt lost is reduced after 7 to 10 days although the water loss remains high (Rittié et al, 2013; Sigal and Dobson, 1968). The sweat gland activity increases during puberty and reduces with ageing renders infants and the elderly susceptible to the effects of excessive moisture on skin (causing nappy rash) (Tian et al, 2000). The glands involved in this process; the eccrine gland which secretes oil through the ducts of the skin pores and the apocrine gland secretes oil through the pores of the hair (Rittié et al, 2013). The sebaceous gland secretes an oily substance into the hair follicles and emerges on to the skin surface via the ducts or pores. The sebum is responsible for water proofing the skin, contains a bactericidal and fungicidal agent, prevents invasion of microbes and prevents drying or cracking of skin (Blanpain and Fuchs, 2009).

1.1.2 v Effects of vasodilation and heat loss

Most heat loss happens through the skin, and small amounts in the urine, faeces and expired air. Only heat lost through the skin can regulate and maintain body temperature. This tissue of the subcutaneous layer is connected to the dermis and contains adipose tissue which has a plexus of blood vessels consisting of arterioles and venules which are innervated by the sympathetic nervous system (Tortora and Derrickson, 2011; Drake, Vogl and Mitchell, 2010; Ham, Aldersea and Porter, 1998). The contractive and dilative properties of the vessels provide blood pressure and volume control which is effective in regulation of the skin temperature. Underneath this lies a deep fascia which contains the underlying tissues of muscles and bones (musculoskeletal structures) (Tortora and Derrickson, 2011; Drake, Vogl and Mitchell, 2010). An increased heat production due to exercise, or restriction on skin (clothes or pressure from a seat surface) or the surrounding atmosphere causes the body temperature to rise and allows the arterioles to dilate causing more blood to rush into the vessels (Tortora and Derrickson, 2011; Ham, Aldersea and Porter, 1998). Extra blood flow near the surface causes increased heat loss through evaporation, radiation (exposed parts radiate heat away from body), conduction (clothes and objects or surfaces in contact with the skin take up the heat) and convection (air passing over exposed parts of the body is heated and rises, cool air replaces this and a convection current is set up). Air is a poor conductor of heat and air trapped between skin and clothing act as an effective insulator against excessive heat loss (Tortora and Derrickson, 2011; Drake, Vogl and Mitchell, 2010; Ham, Aldersea and Porter, 1998).

1.1.2 vi Effects of vasoconstriction and heat production

If the external temperature is decreased then the arterioles constrict to conserve heat energy. If the body is at risk of losing its temperature, the skeletal muscles contract (shiver) to produce large amounts of heat. After eating the metabolic rate and heat production increases as a by-product of digestion (Drake, Vogl and Mitchell, 2010; Ham, Aldersea and Porter, 1998). The hair follicle is in the subcutaneous layer and the dermis. It is composed of a bundle of smooth muscle fibre attached to several hair follicles and innervated by the sympathetic branch of the nervous system (Tortora and Derrickson, 2011). Tiny bundles of nerve fibres attach to each hair. When the pili arrector muscle contracts it pulls on the hair to make it erect. Due to this the contraction of muscles are involuntary and stressors such as danger, cold, exercise or embarrassment may stimulate the sympathetic nervous system and thus cause contraction however the muscle is not under conscious control. Erect hairs trap air which act as an insulating layer, an efficient warming mechanism when accompanied by shivering (Drake, Vogl and Mitchell, 2010; Ham, Aldersea and Porter, 1998).

1.1.3 The physiological effects at the skin-seat interface

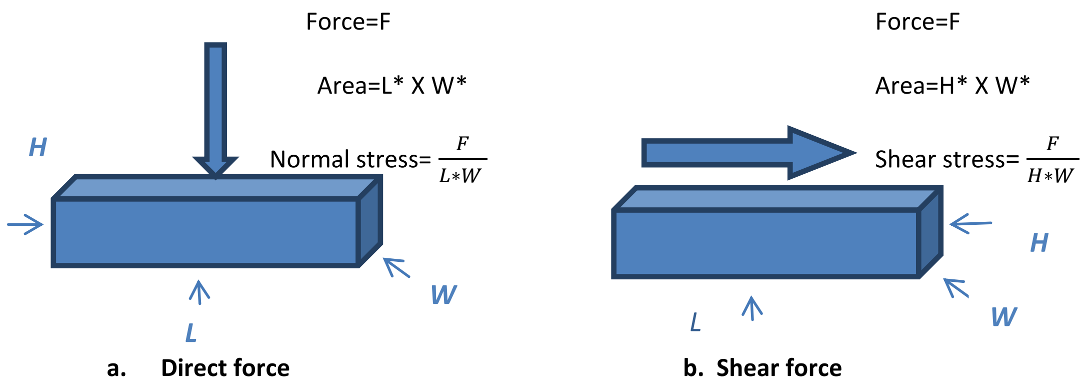
In order to understand the physiological nature of sitting and its potentially damaging effects, it is important to consider the basics of the seated position: pressure, temperature and humidity (Vlaovic, Grbac and Domljan, 2011). When an individual sits on a surface, there is an interaction that may occur between the surface and the body which may determine their comfort, functional and clinical safety (Cooper, 1998). Poor distribution of pressures and moisture control on the seat surface might otherwise lead to skin breakdown (vide infra) (Bardsley, 1993).

1.1.3 i The importance of pressure distribution at the skin-seat interface.

Pressure is essentially the perpendicular force over a unit of area of application (Figure 1.4, a and b) measured in Newtons per square metre (N/m^2), Pascals (Pa) or millimetres of mercury (mmHg). Pressure may also be applied in parallel to the skin surface, contributing to shear stresses that are also measured in force per unit area (Takashi et al, 2010). Normal stresses over bony prominences (such as the IT's) could result in blood flow reduction (ischaemia) leading to the lack of O_2, hypoxia and poor cell nutrition ultimately promoting the death of tissue (Cooper, 1998). If the external pressure exceeds the internal pressures, then normal stresses could occlude capillaries but friction and shear may also cause abrasions on the skin. However shear forces may cause a strain in the body tissue ultimately leading to capillary occlusion as well. If there are shear forces present, then the tolerance for normal stresses is reduced (Bader et al., 2005). At this point other factors that affect tissue integrity (such as moisture increases and poor nutrition) can further exacerbate the problem.

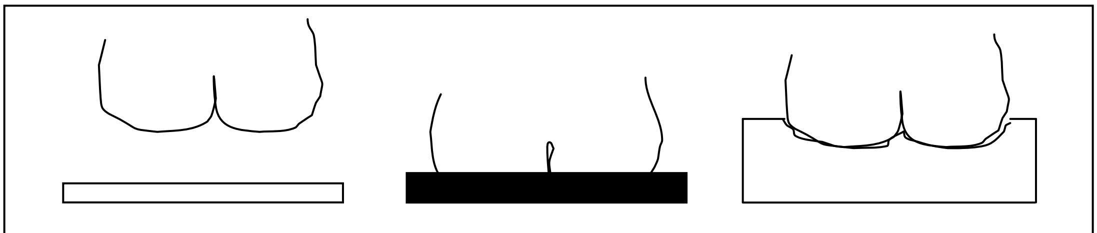
When a person is sitting the total force acting on the buttocks and the thigh area is the mass of the person's body, omitting the supporting forces dissipated via the feet on the leg rest and via the backrests and or armrests of a chair (Ferguson-Pell, 1992; Cooper, 1998). In other words the total sum of forces acting over the entire seating surface should equal the magnitude of the forces applied (Bader et al., 2005; Cooper, 1998). In sitting therefore the body mass should be supported by an appropriate seating interface. Forces that act through the sitting interface will vary by region although this may be influenced by the individual's anatomy, posture, contouring and cushion material (Bader at al., 2005; Ham, Aldersea and Porter, 1998; Cooper, 1998). In addition to the vector forces that occur, the duration of the applied force also affects the underlying body tissues (Cooper, 1998). The human body has the ability to adapt to stresses and during sitting these adaptations may be related to the magnitude, direction and duration of forces applied to the body tissues interfaced with a seat surface (Bader et al., 2005; Cooper, 1998). As a result the shape of a free hanging buttock would ideally be reflected in a seating surface that has deep contouring and compliance in order to reduce and redistribute the internal pressures on the body's seated tissues The response of the body tissues due to the seat surface and contour have been described by two theories as the interface pressure theory and the shape preservation theory (Cooper, 1998; Bader et al., 2005) (Figure 1.5). Pressure that is applied to the skin particularly over the bony prominences causes the distortion of the skin and its underlying soft tissues (Figure 1.6).

Figure 1.4: Direct and shear forces that are involved during sitting



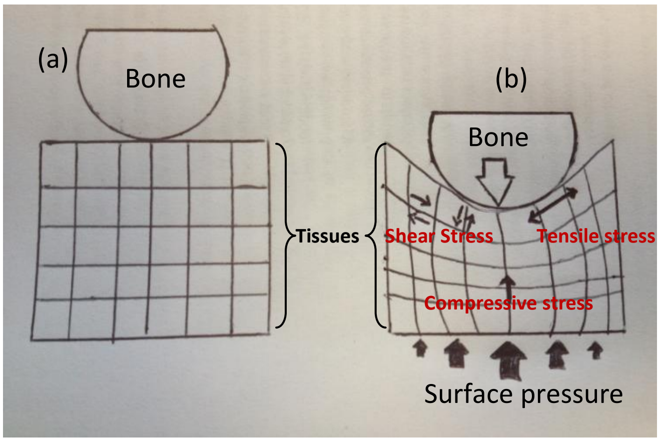
Key: L = Length; F = force; H = Height; W = Width ('X' = multiplication symbol). When a person interfaces with a sitting surface, the stresses acting perpendicular to the skin are referred to as being direct (or normal) stresses or pressure and those that act parallel or orthogonal to the skin are called shear stress or shear pressure (Ferguson-Pell, 1992; Cooper, 1998). Mechanical stress is normally regarded as the effects of pressure in terms of force per unit area (Takashi et al., 2010). Larger mechanical stresses may occur in a number of circumstances such as either the force is acting on a smaller area or if a larger force acts over the same area. Distributing the body mass evenly over the skin contacting the seat will decrease force in any one area thus reducing consequences (Adapted by author from Cooper, 1998)

Figure 1.5: Reaction of buttocks on different surfaces (adapted by author from Cooper, 1998).



Key: The interface pressure theory states that there is a relationship between the internal pressure of the body and the interface pressures exerted on the body by the seat surface. It also implies that some regions of the body tissues are more tolerant to pressures than other regions. It has been argued these differences in region may be represented by pressure gradients that may be measured an act as an indicator of shear forces. These may be measured using pressure measurement devices where the goal is to reduce peak pressures to under '150 mmHg and ensure the distribution of pressures within the seating system (Bader et al., 2005; Ham, Aldersea and Porter, 1998; Cooper, 1998). However recent research suggests that although pressure mapping systems may be routinely used to determine these pressure gradients, it should only be used for educational purposes and clinical expertise should be enhanced to manage seating issues (Dey, Nair and Shapcott, 2013). The shape preservation theory on the other hand assumes that if the free hanging shape of the buttocks is maintained during sitting this constant hydrostatic pressure may result in the minimal occlusion of blood flow thus causing less internal deformation. The disadvantage of maintaining a free hanging shape within a seat is that movement for pressure relief may be interfered (Cooper, 1998). When the body mass of a person is supported by a surface, localised stresses are generated and deform and compress the soft tissues. The pressure risk areas are anatomical sites where there is a thin layer of tissue that covers the bony prominence, examples being: the sacrum, coccygeal region, ischial tuberosities or ITs, greater trochanters, elbow and heels (Posada-Moreno et al, 2011; Maklebust and Sieggreen, 1996).

Figure 1.6: Distortion due to surface pressure (adapted from Takahashi et al, 2010; Roaf, 2006)



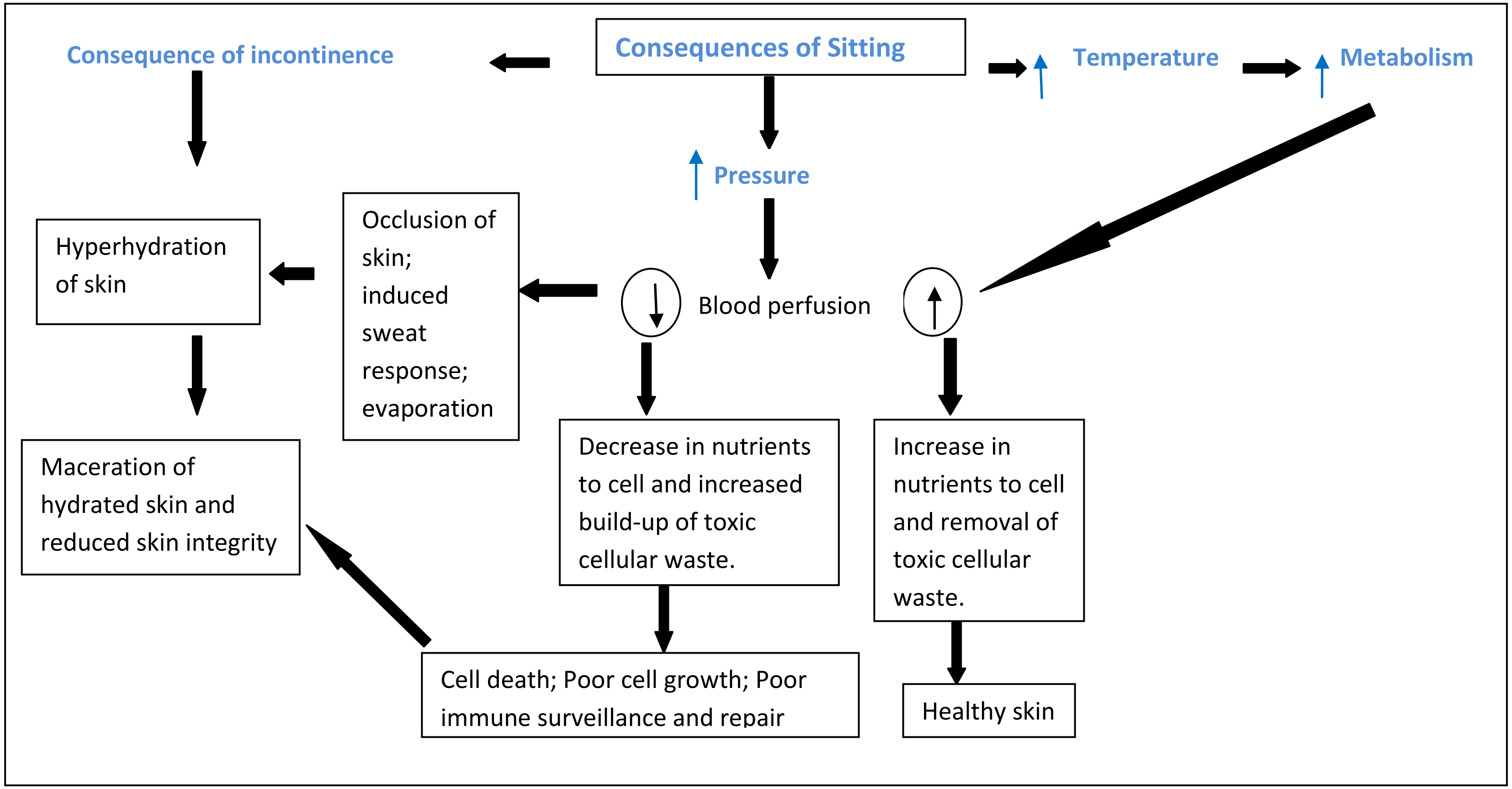
Key: For example when sitting the force of the body mass is focused through the ITs which compress onto the gluteus muscles and the subcutaneous fat. In addition to this the amount of tissue present and muscle tone also determines the deformation that may occur in the fat and muscle. Skin which has been subjected to localised pressures due to sitting will experience some potentially damaging levels of pressure. Initially skin appears pale from the reduction of blood flow and inadequate oxygenation (ischaemia) (Takahashi et al, 2010; Hampton and Collins, 2004).

When the bony prominence comes into contact with a surface (Figure 1.6), the opposing surface pressure causes the horizontal lines (within the tissues) to come closer together, compressing the tissues. Around the bony prominence, there is more elongated stretching (tensile stress) and distorting stresses (shear stresses) that occurs. This gives the indication that pressure is not only a perpendicular force, it may also appear as tensile and shear forces particularly over areas with bony prominences (Takahashi et al, 2010). In a person with normal neurological feedback function, these damaging levels may be recognised and prevented as the effects of the occlusion of blood flow and lymph fluids create metabolites that can stimulate the nervous system and in response, the natural feedback mechanism of a healthy individual will be to shift to remove pressure from the particular location (Ham, Aldersea and Porter, 1998; Drake, Vogl and Mitchell, 2010; Kallen et al, 2011). The compressed region which was originally deprived of nutrients and oxygen and suffered an increased build-up of metabolites will then be replenished with blood. In normal healthy skin, a demonstration of the re-establishment of oxygen and nutrition coupled with the removal of waste products from cells, is called reactive hyperaemia and may be seen in response to pressurising the skin (causing it to appear to be pale) resulting in generalised vasodilatation. Upon removing the pressure, the blood flows back to the previously compressed region which because of the vasodilatation will appear redder and thus will be more noticeable (Drake, Vogl and Mitchell, 2010). The metabolites do not only cause vascular changes, they can also alter neuronal discharge, especially from the nociceptors (chemically sensitive ones in skin, e.g. polymodal nociceptors). This information is used to affect the perception of comfort/discomfort as well as change muscle tone in the body: the result is, fidgeting (Cascioli et al., 2011). Elderly people with less muscle tone or bulk in their gluteal area (tissue stiffness or tone may determine the rate of deformation) are less able to resist tissue deformation (Bader et al, 1995; Hagisawa and Shimada, 2005; Ferguson-Pell, 1992). This is particularly the case in the aged, who have little muscle tone in their gluteal area, are less able to resist tissue deformation, which results in tissue discomfort and tissue damage (NICE, 2005; Posada-Moreno et al., 2011). The elderly usually also have less fat and so this combination of poor padding and inadequate muscle tone may produce higher than normal deformation (Ferguson-Pell, 1992). People who experience prolonged periods of immobility, especially the elderly population and disabled individuals (who are also unable to relieve pressure), are prone to developing loss of sensation. As a consequence of this they are prone to compressing the tissue for longer, which can lead to an increased likelihood of pressure sore formation (Merkelj, et al., 2001; NHS, 2006; Takahashi et al, 2010).

1.1.3 ii The consequence of sitting: humidity and temperature

The combined effects of humidity, temperature and pressure is shown in Figure 1.7. At the interface between the person and seat, the mechanisms of heat and vapour loss may be impeded, causing the skin temperature and humidity to rise and moisture to accumulate between the person-seat surface. Excessive insulation of the seat surface may reduce sensible heat loss (conduction, convection and radiation) and result in over heating and an increase in sweating (Ham, Aldersea and Porter, 1998). If moisture is not able to evaporate then there will be no insensible heat loss (diffusion and evaporation of moisture through skin) and the accumulation of moisture may cause overhydration (Nicholson et al.,1999). Accumulation of moisture or over hydration (Nicholson et al 1999; Ferguson-Pell, 1992) can change the skin properties (Posada-Moreno et al, 2011; Figliola, 2003) by making it mechanically weaker. (Nicholson et al, 1999; Ferguson-Pell et al, 1992). Skin tissue that is mechanically weaker leads to the increase of maceration and excoriation in turn increasing the coefficient of friction between the person and seating area (Nicholson et al., 1999). Moisture from sweating or incontinence will hydrate the skin diluting its natural acidity thus reducing its antibacterial properties; increasing threat to sepsis (Green, 1987). It can also soften the skin causing rapid breakdown of the skin and can be made worse due to shear and friction damages. Bacteria and infection can enter the damaged area, making healing a slow process (Valentin et al., 2006). If the seat surface dissipates too much heat, overdrying could occur causing the skin to dehydrate and become brittle potentially decreasing blood flow following cold induced vasoconstriction (Blank, 1952;Ferguson-Pell et al., 2009). Skin that becomes overheated due to prolonged sitting increases metabolic demand which can further compromise hypoxic areas (Nicholson, 1999; Reger, Ranganathan and Sahgal 2007; Krouskop, 1983; Ruch and Patton, 1965). A reduction in the metabolic demand will occur if the skin temperature decreases however this will cause blood vessel vasoconstriction and thus reducing blood supply to the affected area (Nicholson et al., 1999). Evaporation can cause over drying of the skin leading to peeling and cracking, which can worsen the problems associated with shear pressure (Mündlein et al., 2005; Sekiguchi et al., 2001). This process automatically reduces the skins natural barrier to infection (Tagami, 1980). The demand on local metabolism increases due to the local bacterial increase both by its own needs and the bodys requirements, and this in turn could cause nutritional disturbances and weaken the reserves of the human body. As an example, fever increases the metabolic rate of the entire body (Nicholson et al., 1999). There is a similarity between the skin changes seen in prolonged pressurisation of the skin (maceration and excoriation) and those caused by persistent incontinence (Wounds UK, 2012).

Figure 1.7: Consequence of sitting



1.1.4 The solution: Detecting skin humidity with sensor technology.

Measurement at the interface between the surface of the skin and the surface of the seat or mattress is an important area of research which is revealing those factors implicated in and capable of exacerbating the effects of pressure induced mechanical damage to the skin tissue: inclusive of, but not limited to relative oxygen and nutrient starvation and metabolite (including heat) build up (Cascioli et al., 2011; Lachenbruch, 2010). As alluded to above, there are factors other than pressure that can reduce tissue viability and through this lead to damage and poor healing (Nicholson, 1999). It is more than likely that there could be an interaction between the environment, human body and the properties of the materials comprising the seat such as the seat covers, cushion material and mattress material (Stewart, Palmieri and Cochran, 1980; Ferguson-Pell et al., 2009). The degenerative effects of dementia causes a neurological decline, and along with it, a progresive decrease in communication. This may make it challenging for the person with dementia to indicate their continence status to carers, potentially advocating the need of an alternative form of communication. Sensor detection technology, if used to bridge the gap of communication, can also minimise anxiety and behavioural changes in someone with dementia as they would not be subjected to unnecessary personal space invasion and checking. In parallel to this, carers may feel less stressed about approaching the person with dementia (Upton and Reed, 2005; Getliffe and Dolman, 2007; Rodriguez, Sackley and Badger, 2006; Van Den Heuvel, Jowitt and McIntyre, 2012; Price, 2007; Price 2011; Hagglund 2010; Brodaty and Donkin, 2010; Edvardsson, Winblad and Sandman, 2008; Darton, 2008; Thomas et al., 2004; Etters and Harrison, 2007). If a person cannot detect the change related to early stages of skin damage (provoked by skin moisture from UI or sweating) assistive sensor technology might be of benefit here also(Lu, Xueheng, and Emery, 2013; Cascioli et al., 2011).

1.2 Study outline

It is the link between the underlying body condition and state of technology that will form the basis for addressing this study. People with dementia are often faced with lack of communication skills putting extra responsibility on the carers to know what their needs are. If the person cannot detect the change related to early stages of skin damage, non-invasive sensor technology could be of benefit. However, such assistive technology requires an understanding of the best placement of the detectors (sensors). The purpose of the study described in this thesis is to substantiate the feasibility of sensor technology for humidity measurement to overcome communication barriers between carers and residents and to fathom its use within management. The emphasis will be to learn more about the limits of the sensor seat material combination and ensure the limits of capability of the measurements are not influencing that which they purport to measure. This extends from the study by McCarthy et al., (2009) where the short term reliability and characteristics of the sensors were studied. This study will also address the interface effects of sitting by human subjects on a seat cover and sensor combination. This leads on to exploring the research problem that this study will address which could give an insight into the interaction between temperature and humidity in sitting and how technology might be best used to address this. The research thesis adopted a mixed methods approach in initially carrying out a series of telephone interviews and questionnaire survey followed by a series of laboratory experiments looking at aspects of measuring and calibrating relative humidity sensors during sitting. The telephone and questionnaire surveys investigated how the application of sensor technology could be used by carers of people with dementia and UI in care homes. This involved obtaining carer views regarding current urinary incontinent management protocols; through telephone interviews and with the subsequent deployment of a questionnaire survey. In parallel to this specific laboratory experiments were conducted to explore the aspects of the application of sensor technology from three broad perspectives such as: sitting experiments, testing the sensors in a laboratory setting and regularly calibrating the relative humidity sensors within an environmental chamber (traceable to National standards). Based on the previous literature review it is evident that specific sensor technology design may be achieved to match the desired needs of carers who are directly involved with the care of incontinent dementia sufferers. Since this is the case, the research presented here aims to address the following research objectives (Table 1.1) in order to address the research questions. This study will principally explore the current state of acceptance for use of technology in private care homes and conduct appropriate laboratory and calibration experiments to determine the technological configuration and compatibility of a sensor based solution.

Table 1.1. Outline of chapters with their respective aims, objectives and research questions.

Title	Aim	Objective	Research question
Chapter 2 ***Perceptions on using sensor technology to manage incontinence in dementia***	To understand carer perceptions on using sensor technology to manage incontinence in dementia residents in care homes.	To find out the carer's perceptions on use of sensor technology to assist with current management	Is there a perceived need for sensor technology when examining the methods and experience of carers in the management of dementia residents with incontinence?
Chapter 3 ***Performance verification of humidity sensors traceable to national standards.***	Sensors inside a material cover will be used to demonstrate reliability, accuracy and feasibility of using such a combination through testing and calibration	To investigate the reliability and accuracy of relative humidity sensors within a traceable calibration chamber and over long term use in a laboratory.	What is the reliability and accuracy of sensors when used in different environments for prolonged periods of up to seven months?
Chapter 4 ***Application of the sensors in a simulation of care home sitting activity.***	To objectively assess the biological measures of humidity in sitting without invasive human contact (embedded in seat below the person sitting). To also consider the most appropriate place to site the sensors.	To observe the levels of change in humidity during prolonged sitting experiemnts and a sit and stand activity.	Where is the most appropriate placement for the sensors when measuring human subjects in sitting?
Chapter 5 ***Synopsis of results, general thesis discussion, and conclusions***	To determine the suitability of a sensor detection device and an ideal prototype.	To connect all chapters together and outline the components resulting in a basic prototype.	How would an ideal prototype design be identified so that it could be successfully applied in the home care setting?

Chapter 2

Perceptions on using sensor technology to manage incontinence in dementia

"Ageing is inevitable from the minute we are born; we are all on the same journey. It's what we do in between to manage the process of ageing that counts" - Maya Angelou

The scope of this chapter is to establish managing techniques used by carers for the care of incontinence in people with dementia. Understanding management protocols will help recognise the perceived usefulness of using sensor detection technology within the care home environment. Perceptions of carers were investigated through surveys. Although rudimentary, data from carers could support the interest for an incontinence detection device that could aid with care home management. This has the caveat that the outcome of the questionnaire will determine the constraints that will affect the testing and design (consequent chapters) of a device and its usefulness to monitor humidity changes due the occurrence of incontinence.

2.1 The progression of incontinence in dementia

Dementia is a neurological degenerative condition that affects the brain function and progresses to decline with time (Phair and Good 1998; Kitwood and Benson, 1995). This eventually causes sections of the brain (cognition and organ function) to deteriorate inevitably reducing the function of the organs in the body, such as respiratory, cardiac and the urinary system (Brown and Hillam, 2004; Drake, Vogl and Mitchell, 2010). UI in people with dementia may occur at an early stage (functional disability: the lack of cognitive function to allow the person to understand what needs to be done when they need the toilet) and at a late stage (where the urinary system itself is affected structurally and physiologically) (Brown and Hillam, 2004; Phair and Good 1998; Kitwood and Benson, 1995). The loss of bladder control particularly happens to many people in the later stages of dementia whether the occurrence of UI is all the time or the occasional leaks (Brown and Hillam, 2004). Incontinence is not an inevitable symptom of dementia but there are a number of medical reasons why someone with dementia could become incontinent (Brown and Hillam, 2004; Getliffe and Dolman, 2007). These possible medical causes include urinary tract infections, severe constipation, side effects of medication or pharmacological interventions, prostate gland trouble, forgetting to go to the toilet or not recognising the need to go (Alzheimer's UK, 2013). Cognitive skills are required for successful toileting which may break down for people with dementia. Losing the skill of communication and understanding may cause feelings of fear and frustration to build up (Brown and Hillam, 2004; Getliffe and Dolman, 2007). Communication may then be relayed through behaviour (identified as restlessness, or physical aggression) however this has been commonly referred to as 'challenging behaviour' (Kitwood and Benson, 1995). Obtaining information about a dementia person's UI directly from them may be difficult and should be sought from family and carers involved. The presence of UI at any stage of dementia can cause a lot of distress as well as harm to the individual by potentially causing unnecessary sores due the ageing skin's exposure to skin surface moisture and surrounding high levels of humidity (Abrams et al., 2003; Abrams et al., 2009). A good knowledge of the normal function of the human brain and the urinary system is important to help understand dementia and how UI develops in tandem.

2.1.1 The normal human brain

The human brain is a complex structure consisting of two basic components: the grey and white matter (Toro et al., 2008). Grey matter is composed of neurones (nerve cells) which communicate with each other by releasing chemical transmitters (neurotransmitters) on the surface of other neurones where specifically sensitive receptor sites are located (Thompson, 2000). The neurotransmitters include acetylcholine, glutamate, dopamine, serotonin and noradrenaline which are involved in the regulation of memory, mood, sleep, appetite and behaviour (Simon, 1999; Ramachanandran, 2011; Cantley, 2001). Glial cells support the grey matter by supplying nutrients to the neurons and repairs damage cells. This support for maintenance is important because neurons cannot duplicate themselves (Buxton, 2002; Campbell, Neil and Reece, 2005; Cantley, 2001). White matter of the brain consists of fibres that connect neurones to one another and allows rapid communication over short or long distances (Preissl, 2005; McGilchrist, 2009; Kandel, Schwartz and Jessel, 2000). Complex networks of these fibres enable the neurons to influence the activity of hundreds and thousands of neurons (Cantley, 2001). The grey and white matter are organised into four major anatomic regions (or cortical lobes) collectively referred to as the cerebral cortex (Toro et al., 2008; Cantley, 2001). These four cortical lobes are the temporal lobe, frontal lobe, parietal lobe and occipital lobe (Campbell, Neil and Reece, 2005). The temporal lobe regulates memory and mood. The hippocampus (inner medial structure) is involved in learning new information. The frontal lobe (anterior part of temporal lobe) controls the understanding of language and meaning. It influences the production of speech, personality traits, decision making, complex behaviours and judgement (Ramachanandran, 2011; Preissl, 2005). The parietal lobe (located superior and anterior) is involved in tactile and visuospatial perception of the individual self (self-image) and the outside world through proprioception and direction (Cosgrove, Mazure and Staley, 2007). They are also involved in the complex motor tasks such as cooking or dressing (Cantley, 2001). The occipital lobe (located posteriorly) processes incoming visual stimuli. Under the cortical lobes lie the cerebellum which is responsible for the coordination of balance, posture and movement of the body (McGilchrist, 2009; Kandel, Schwartz and Jessel, 2000). The mid brain and brain stem regulates basic functions such as sleep, appetite, continence and sexual function (Buxton, 2002; Campbell, Neil and Reece, 2005).

2.1.1 i Ageing of the human brain

Losing the function of the neurones in each lobe of the brain means that the individual would lose function in that region (Craik and Salthouse, 2000). Damage to the frontal lobe would exhibit difficulty with talking, decision making or lack of initiative (Raz and Rodrigue, 2006) which could affect a simple life skill such as going to the toilet. The connections between neurones continue to increase through adult life and probably forms the basis for the establishment of patterns of behaviour and the acquisition of knowledge (Kolb, Gibb and Robinson, 2003; Barnes and Burke, 2006). The brain mass developed from birth to adolescence reaches to about 1500-2000g (Anderton, 2002; Whalley et al., 2004). From the fifth decade onwards grey matter begins to slowly diminish in volume however the effects upon mental function are generally negligible because the brain has a considerable 'reserve capacity' (Hof and Mobbs, 2009). Due to normal ageing a healthy 70 year old may have lost up to 10 - 15% of brain mass. This has minor impact on the ability to learn new information, names of new acquaintances, and with no reduction in previous knowledge or wisdom (Kensinger, 2009; Hall et al., 2009). The normal ageing brain does accumulate some degenerative and vascular changes over the years, and seen as small decrements in short term memory and new learning ability that are common in older people (Anderton, 2002; Barnes and Burke, 2006). Dementia occurs when the disease progresses to a greater degree of neuronal damage or loss, for example when white matter connections are severely interrupted or due to a combination of these events (Alzheimer's Society, 2013). Although increasing age is the most important known development risk factor, dementia is not generally held to be part of the normal ageing process (Getliffe and Dolman, 2007).

2.1.1 ii Dementia pathology

Multiple neuropathological processes may underlie dementia, including both neurodegenerative diseases and vascular disease (Brown and Hillam, 2004). In addition, comorbidity is the criterion rather than the exception for dementia in elderly persons (Montine et al., 2012). As well as progressive, dementia can also present non-progressive symptoms that include memory loss, difficulties with thinking, problem solving or language which would affect mood and behaviour (Alzheimer Society, 2013). Progressive dementia may be commonly caused by neurodegenerative diseases such as Alzheimer's disease, frontotemporal dementia and dementia with Lewy bodies (Wakisaka et al., 2003; Ratnavalli et al., 2002). In these diseases there is gradual change due to damage of brain cells (ultimately cell death) caused by a build-up of abnormal proteins in the brain (Mayo Clinic, 2005). In Alzheimer's disease the loss of brain cells causes the brain to shrink (particularly affected by the cerebral cortex), medically known as 'atrophy' (Shub and Kunik, 2009). Abnormal proteins formed are called plaques and tangles which are responsible for interfering with the neurotransmitter chemicals that carry messages between brain cells (Forbes et al., 2013). Frontotemporal dementia is caused by a genetic inheritance that causes the frontal and temporal lobes of the brain to shrink and is commonly seen in people under the age of 65 (Wakisaka et al., 2003). Motor neurone disease sometimes associated with frontotemporal dementia is a rare condition that progressively damages the nervous system, causing the muscles to waste away (Brown and Hillam, 2003; Forbes et al., 2013). Dementia with Lewy bodies is similar to Parkinson's disease where brain cell damage over a number of years leading to physical symptoms such as involuntary shaking or tremors (Ratnavalli et al., 2002). Another form of progressive dementia is vascular dementia caused when there is an interruption in the blood supply to the brain (causing brain cells to die resulting in brain damage) which can occur due to strokes (Lee, 2011; NHS Choices, 2013; Alzheimer's Society, 2013). Interruptions of blood can also occur when blood vessels narrow and harden due to fatty deposit build-up commonly known as atherosclerosis (Alzheimer's Society, 2013). This is common in people who have high blood pressure, type 1 diabetes and those who smoke. Other rare causes of neurodegenerative conditions include Huntington's disease (a genetic condition which causes brain damage), progressive supranuclear palsy and posterior cortical atrophy which is an unusual form of Alzheimer's affecting the vision rather than memory (NHS Choices, 2013). Non-progressive dementias do not continue to get worse over time and are caused by depression, HIV- related infections, some brain tumours, lack of vitamin B in the diet, lack of thyroid hormones, head injury and long term alcohol misuse (NHS Choices, 2013; Alzheimer's Society, 2013).

2.1.2 Pathophysiology of UI in dementia

Research on urinary incontinent nursing home residents has consistently supported an association between UI and dementia (Abrams et al., 2009). In studies using multivariate analyses, patients lacking mental orientation had a 3.6 times greater risk of being incontinent than those with normal mental status and the presence of dementia increased the odds of UI by 1.5 to 2.3 times (Abrams et al., 2009). In other words the prevalence of incontinence is notably higher in people with dementia (53%), compared to those without dementia (13%) (Miu et al., 2010; Price, 2011). People diagnosed with dementia have about three times the rate of a diagnosis of UI compared to those without a diagnosis of dementia (Grant, 2013). Furthermore, patients with dementia and incontinence were more likely to receive incontinence medications and indwelling catheters than those with incontinence but without dementia (Grant, 2013). Knowledge of the normal function of the urinary system is important to help understand how UI impacts on people with dementia.

2.1.2 i The normal urinary system

The urinary system is the organ in the body responsible for the storage and periodic elimination of urine (Getliffe and Dolman, 2007). The major anatomical structures involved are the bladder and the lower urinary tract. The maintenance of continence involves a complex process of neuromuscular coordination to regulate switching between the elimination of urine and storage (Ham, Aldersea and Porter, 1998). For elimination of urine, the parasympathetic pelvic nerves (cholinergic nerves) allow the bladder (detrusor muscle) to contract and the urethra to relax to allow for the urine to be removed (Heuther and McCance,2011; Dugdale, 2011). For storage the sympathetic hypogastric nerves (adrenergic nerves) causes the bladder to relax and the urethra to stay shut so that urine is not eliminated (Anthea et al., 1993; Caldwell and Young, 2006). Pudendal nerves are the somatic nerves that innervate the pelvic floor muscles and therefore allow the conscious control over them (Getliffe and Dolman, 2007). The micturition centre located in the spine (between the sacral region: S2 and S4) communicates with the pontine micturition centre in the brain (cerebral cortex and the brain stem or the pons) using both sensory neurones (transmit signals of bladder fullness) and motor neurones (signals the actions of contraction or relaxation) so that the voiding and storage of urine are carried out effectively (Mader, 2004; Smith, 1998). When the urine in the bladder has reached an approximate capacity of 150 ml to 250 ml, an awareness of distension and mild desire to void is usually experienced although this can be supressed by conscious inhibitory control from the cerebral cortex until a suitable time and place to void (Getliffe and Dolman, 2007). The average bladder capacity is about 500 ml although this is dependent on age, health and the physical stature of individuals (Getliffe and Dolman, 2007). The low location of the spinal micturition centre makes it vulnerable to dysfunction due to damage of the spinal cord above this level (Graaff, 2002; Mader, 2004). Effective function of the urinary system is dependent on the neural networks extending between the sacral spinal cord and the cerebral cortex (Caldwell and Young, 2006; Nielsen, 1990; Ham, Aldersea and Porter, 1998). Therefore changes in the lower urinary tract function are commonly early signs of a number of neurological diseases (Getliffe and Dolman, 2007).

2.1.2 ii The ageing effects of the urinary system

It is important to point out that with the exception of neurological dysfunction and spinal cord injury, older people have the highest known prevalence of UI or faecal incontinence of any group (Getliffe and Dolman, 2007). The association of incontinence with ageing may stem from the elderly being more susceptible to physiological, pharmacological and psychological risk factors which may influence their ability to remain continent (Hirakawa et al., 2013; Shamliyan et al., 2012). UI is a common symptom that may affect people of all ages and it is not a life threatening disease. In people with dementia particularly it can have a negative impact on the physical, psychological and social wellbeing of the affected individual (Stothers, Thom, and Calhoun, 2007; Karlovsky, 2010). Age related changes in the urinary system commonly causes fluid balance disorders which can present clinically as urinary frequency, nocturia and incontinence (Miller, 1999). Ageing changes can occur in the renal and hormonal systems that control the excretion of sodium and water along with changes in the reservoir size of the bladder (Miller, 1999). Functional bladder volume concurrently decreases in the elderly patient. The combination of increased urine production at night and decrease in functional bladder volume results in the development of nocturnal urinary frequency and predisposition to the development of UI (Ham, Aldersea and Porter, 1998; Miller, 1999). A circadian pattern to urine production exists in young and healthy people (Nakamura et al., 1996). This allows less urine flow rate in the night times than in the day time (Miller, 1999). In the normal ageing process there is an increase in urine production at night, resulting in the urine flow rate either equal or exceeding the day time urine production rate. Carcadian patterns are maintained until around the age of 60 years (Nakamura et al., 1996). At this point a greater amount of urine production occurs in the night time (Miller, 2009). People with dementia may experience diminished AVP hormone secretion (AVP or arginine vasopressin is an antidiuretic hormone responsible for the regulation of urine formation) which puts this population at risk for nocturnal polyuria syndrome and incontinence (Nakamura et al., 1999; Miller, 1999; Getliffe and Dolman, 2007). The risk is even greater when they experience diminished perception of bladder fullness and/or impaired mobility (Getliffe and Dolman, 2007). Treatment options usually involve the administration of hormone replacement in the form of intranasal or oral (DDAVP; desmopressin or lysine vasopressin) as an effective intervention to reduce nocturia and incontinence and the clinical consequences related to this disorder (Miller, 1999). The neurological degenerative nature of dementia means that cells of the grey and white matter will diminish, therefore interfering with the neurotransmission chemicals. This will disrupt the communication between the urinary system and the brain and present problems with continence (Getliffe and Dolman, 2007). UI is a symptom with many causes, but failure to adequately diagnose, treat and support those with a continence problem robs people of their dignity and imposes limitations on lifestyle and social functioning (Shamliyan et al., 2007; Walid and Heaton, 2009). Embarrassment and ignorance about the subject prevent many people seeking help (Price, 2011). However with correct diagnosis and appropriate treatment, incontinence is a condition that can often be cured and mostly improved often by relatively simple non-invasive methods delivered outside of hospital settings (Nygaard et al., 2003; Hannestad et al., 2000). Incontinence continues to be a significant problem worldwide affecting the lives of millions of individuals and families with associated impact on quality of life and burden on health and social care services (Shamliyan et al., 2007; Walid and Heaton, 2009). Due to the global increase in the ageing population, the absolute number of older people with UI is increasing exponentially (Balter, 2003; Roe et al., 2010).

2.1.3 Prevalence of dementia and UI in the UK

In the UK, the prevalence rate of dementia according to the elderly population (65 years and over) and the frail elderly (80 years and older) are tabulated on Table 2.1. In terms of projected growth, it is estimated that by 2021 there will be one million people with dementia in the UK. This is because of the relatively large increase in the number of older people who are most at risk of dementia (Alzheimers Society 2007; (Price, 2011). This is expected to rise to over 1.7 million people with dementia by 2051 (Alzheimer’s Society, 2013).

Table 2.1: Dementia prevalence rates in the United Kingdom

Age group	Population with dementia (%)
65 – 69	1.3
70 – 74	2.9
75 – 79	5.9
80 – 84	12.2
85 – 89	20.3
90 – 94	28.6
95 and over	32.5

Key: **The percentage of dementia in the population has been categorised according to 5 year age intervals between 65 years and 95 years or older. It can be seen that the occurrence of dementia increases with age. Dementia does occur in younger people between the ages 45 years to 65 years however the prevalence is very low with an estimated rate of lower than 0.1 % of the population (Knapp et al., 2007). It appears that the prevalence of dementia increases with age however this relationship has not been discussed in this study.**

2.1.4 Microenvironment at the skin and seat interface of the elderly

Within the person-seat interface microenvironment, moisture from sweat and UI could cause skin maceration which in turn can weaken already damaged skin (Ferguson-Pell, *et al.*, 2009) and this can be presented as a problem in the elderly (commonly observed in people with dementia) (Macdiarmid, 2007; Dubeau, Simon and Morris, 2006; Fultz et al., 2005; Burgio, 1990). The level of humidity at the person-seat interface due to incontinence and sweating in relation to a variety of other factors could predispose the individual to pressure sore formation and skin infection (Donovan et al, 1993; Maklebust and Sieggreen, 1996; Wu et al., 2009). Constant and increased moisture from urine contact, spilt water (drinks) or sweating can reduce the proper maintanence of tissue health and open it to fungal or bacterial infection (Tsai and Chen, 2010). The increase in humidity in the sitting area can make micro-organism growth more likely and worsen the condition (Figliola 2003; Ferguson-Pell et al., 2009; Reger et al., 2007; Romanelli et al., 2006). The microorganisms that are on the skin surface (such as bacteria, fungi and yeast) will feed on trapped sweat and dead skin cells and multiply. It is this increased microbiological activity that can cause a risk of infection to ulcers (Nicholson, 1999; Sugarman, 1985; Torrance, 1983). Although "normal" urine is relatively sterile and bacteriostatic UI from an individual with urinary tract infection will carry bacteria which can infect wounds placing demands on the body's defence mechanism (Nicholson et al., 1999; Getliffe and Dolman, 2007; Cengiz and Babalik, 2007). A problem that needs addressing is the delay in response to UI (of dementia residents) which could cause a person to lie in a soiled pad for a long period of time, leading to discomfort, confusion, distress, embarrassment and possible skin breakdown (Nicholson, 1999; Ferguson-Pell et al., 2009; Wai et al., 2008; Wai et al., 2010; Bichard et al., 2012; Schneider et al., 2011).

2.2 Background to the study

The following four sections describe the experiences of both carers and dementia suffers in relation to the management of UI within a care home setting. It will explain what the issues in management are, the current management methods, the general perceptions of using sensor technology for UI detection and the desired design of sensor technology.

2.2.1 Management methods and the issues.

UI is part of the issue that is faced in all health related services (NHS choices, 2014; CG40 NICE Guidelines, 2006) and it has its burden on cost and care management protocols especially due to people with dementia residing in care homes. The problems identified in care homes include, variations of treatment, challenges in dealing with people with dementia, number of staff and quality of education or training (Department of Health, 2000; Zimmerman et al., 2005). Treatments for incontinence in people with dementia include the use of drugs or surgical procedures (for mechanical incontinence) or behavioural techniques (for functional incontinence) although continence containment products remain the most viable option (Schnelle et al., 1990; Bravo, 2004; Ostaszkiewicz et al., 2005; Roe et al., 2006; Tanaka et al., 2009; Long et al., 2010; Roe et al, 2010). Anticholinergic and smooth muscle relaxants have been common pharmacogical interventions used to reduce detrusor hyperactivity however they pose concern as they may worsen constipation and cognition, and also raise the risk of delirium in the person with dementia (Tannenbaum and DuBeau, 2004; Yap and Tan, 2006). A popular drug for overactive bladder called Tolterodine, has shown no medical evidence of central nervous system side effects however, drug inducing risk to delirium has been reported (Malone-Lee, Walsh and Mangourd, 2001; Yap and Tan, 2006). Behavioural techniques involve individualised toileting programs in order to recognise personal patterns, pre-empting micturition or defecation. This technique is widely used and works well at minimising incontinence but it is quite labour intensive for the carer (Burgio et al., 1990; Mathur, Browning and Mistri, 2010). There are several different methods commonly used to provide assistance with toileting for the management in UI in the elderly (Roe, 2010). These interventions include prompted or times voiding, habit training, biofeedback, pelvic-floor muscle training, bladder training and the use of containment products (such as incontinent pads or commodes) (Fader, 2008; Ostaczkiewicz, 2004). In people with dementia there has been little data reported that support the use of pelvic floor exercises, biofeedback and electrical stimulation which have been shown useful in people without cognitive impairment (Yap and Tan, 2006). In the long term care setting timed voiding has been commonly promoted in the elderly who have cognitive and motor deficits (Ouslander 1985). This is because this passive form of toileting assistance is suitable for residents who cannot participate in independent toileting (Fantl, 1991). This method intends to avoid UI however it does not promote the restoration of bladder function (Ostaszkiewicz, Johnston and Roe, 2009). In the care home environment, routine checks and toileting regimes are commonly adopted by carers however urinary accidents sometimes remain undetected for long periods of time and may only be resolved at the next check. Furthermore, incontinent pads (used as the main containment product) still pose problems to leakage. This suggests that containment strategies do not aim to encourage continence and may result in indiscriminate use of pads and unnecessary referrals to expensive services (RCP 1995). Better understanding of technology and products to improve lifestyle might prevent the use of pads and encourage the promotion of continence (Wai et al, 2010; Getliffe and Dolman, 2007). The high staff turnover rate in care home means that carers are not always familiar with resident's individual needs or ways of expressing incontinence related distress (Ross, 2011). Cognitive impairment present in people with dementia could cause lack of cooperation that may affect management of UI by care givers (Jirovec and Tempin., 2001; Jirovec and Wells, 1990; Ouslander et al., 1990; Thomas et al., 2004). Delays in responding can impact significantly on the quality of life but can also compromise skin integrity leading to skin maceration and pressure sore formation (Wai et al., 2008). The dementia sufferer may view attempts to maintain continence and hygiene as intrusive, which potentially can result in behavioural problems such as resistance and aggression (Yap et al., 2006).

2.2.1 i Perceptions of using technology

Technology to monitor health has been reported to deliver significant benefits in terms of enhanced care provision and improved quality of life for people with dementia also reducing some of the pressure on local health authorities and care providers allowing them to deploy resources efficiently and cost effectively (Buckley 2006; Glasper, 2011; Potts and Earwicker, 2011; Barlow, 2006, Kang et al., 2010). Effective communication is the key to alleviating problems in caring for people with dementia (Yap and Tan, 2006). Carers were reported to be less stressed as a result of using technology, and improvements were found in the well-being of those being cared for (Woolham, 2005). Technology should be developed with the proper understanding of the specific needs of the adults and what would be useful to the carers (Kang et al., 2010; Miskelly, 2001; Biswas et al., 2008).

2.2.1 ii Perceived usefulness of a sensor based solution.

Technology to measure the humidity effects of prolonged sitting and lying is currently evolving (Sakoi et al., 2007; Wai et al., 2010; Bharucha et al., 2009; Cengiz and Babalik, 2007; Miller et al., 2001; McCarthy et al., 2009; Cascioli et al., 2011). In order for this technology to be applied successfully there must be an understanding of what is objectively happening (Kokate et al., 1995; Cengiz and Babalik, 2007; Dorsten, 2009; Bupa, 2011; Watson et al., 2003; Aslam et al., 2009; Robinson, 2000; Lachenbruch, 2010; Cascioli et al., 2011). During sitting prolonged exposure to increased humidity and liquid (from UI and sweating) are known to exacerbate the mechanical effects of pressure on skin viability (Bader et al., 2005; Nicholson et al., 1999). If a person cannot detect the change related to early stages of skin damage (provoked by skin moisture from UI or sweating) assistive sensor technology might be of benefit (Lu, Xueheng, and Emery, 2013, Cascioli et al., 2011). Such technology requires an understanding of the optimal placement of the detectors (McCarthy et al., 2009; Liu et al., 2011). There is a strong objection to the use of products that have a wired connection attached to the patient since it affects the safety, comfort and in some instances the mobility of the patient (Biswas, 2008). Bulky sensors embedded or attached to the pads invasive to the human body are not desirable and sensing components need to be as small, flexible and thin as possible like RFID tags (Biswas, 2008). Carers are often not interested in products that require extensive cleaning or technical management. As a result they tend to retreat from the prolonged use of such products and therefore do not give technology a chance. The benefits of technology for people with dementia in care homes, may be poorly understood or explored and is often limited to the traditional nursing call systems where residents are able to notify carers when needed (Wai et al., 2010), although declines in cognition of the dementia resident will eventually prevent them using this type of technology. Carers commend traditional approaches to maintaining continence (Shah et al., 2010; Upton and Reed, 2005) although it was found that many perceive sensor detection technology could avoid delays in checking and limit intrusion on dementia residents who are already unaware of their deficits (Miskelly, 2001; Bharucha et al., 2009) . A carer's visit to check soiled pads may be reduced by as much as 50% through the use of an automated incontinence detection system (Gregg et al., 2004; Lachenbruch, 2010). Due to the neurological nature of the disease (Price, 2007; Price 2011; Hagglund 2010; Brodaty and Donkin, 2010; Edvardsson, Winblad and Sandman, 2008; Darton, 2008; Thomas et al., 2004; Etters and Harrison, 2007) and the progressive lack of communication (making it challenging for them to indicate incontinence) people with dementia could benefit from this type of technology (Wai et al., 2008; Miskelly, 2001).

2.2.2 Outline of the study.

The central point in this research was to understand the current management methods and issues in care homes to emphasise the application of sensor technology for detecting UI in people with dementia. This includes investigating a number of related aspects such as perceived usefulness of sensor technology and the inclusion of carers on a desirable design of a detection system. This will be used to substantiate the feasibility of non-invasive sensor technology for humidity measurement (developed through proof of concept by McCarthy et al., 2009) to overcome communication barriers between carers and residents and to fathom its use within management. Many studies have been carried out with the aim of detecting UI using body temperature but not on humidity (Pandey et al., 2013; Cusick et al., 2003; Wang et al., 2009) The subsequent sections present the methodology used to investigate the aims, objectives and research question (Table 1.1) of this study with regards to managing incontinent dementia care home residents. Determining the level of acceptance of carers regarding use of technology will help to create a compatible detection system that would suit the caring environment. The testing, design and application on human subjects will help to confirm the suitability of such a device and will be explored in chapters three and four.

2.2.3 Methodology

A cross sectional study was conducted on private care homes (with dementia care facilities) in England and Wales (Shah et al., 2010) using two qualitative methods; a telephone survey (between June 2011 and December 2011) and a questionnaire survey (between January 2012 and May 2012). The results of the telephone and questionnaire surveys had the caveat that the outcome would determine the constraints that will affect the design of the final device prototype and its usefulness to monitor changes due the occurrence of incontinence within the sample population. Although privately owned care homes with dementia care facilities were approached, the study was focussed on the carer's perception on management in relation to residents with dementia who have UI. Carers are in direct contact with dementia residents and therefore they were thought to be the best people to interview. The term care home has been suggested to be generic for describing institutional community homes that provide long-term care for the elderly. This includes nursing homes (provision of nursing care), residential care homes (mainly providing social care that is more independent than nursing care) or dual registered homes (these provide both residential and nursing care) (Roe et al., 2011).

2.2.3 i The telephone survey

In the telephone survey a crib sheet containing a series of short closed and open questions (Appendix 1a) was used for establishing the willingness to participate as well as to clarify the purpose and prepare participants for the questionnaire survey. The author called a list of private care homes in England and Wales that have dementia care facilities and requested to speak with a care manager or a senior carer, both with experience in working with dementia residents who are incontinent. Questions from the crib sheet were used during the interview and indicated if there was interest in them pursuing the next stage of study which is the questionnaire survey. Response from the telephone survey enabled the semi-quantitative questionnaire to be designed investigating current methods used to manage UI in people with dementia and to obtain carers views on the potential use and design of technology to facilitate their role. The telephone survey questions in the 'crib sheet' were developed through independent study by the researcher as well as advice and discussion with a business solutions company 'Evolution IS' using their 'voice of consumer' (VOC) methodology. The VOC methodology is a method used to identify customer needs and requirements through actual customer interactions such as telephone interviews (Abbie and Hauser, 1993; Katz, 2001). The technique is useful in obtaining instant feedback from the people who are in direct use or in need of a product or idea. The telephone surveys (crib sheet) consisted of four questions (items were clustered around 4 main themes): (1) describe the challenges faced with the management of incontinence; (2) would a detection device help with management?; (3) how could the device alert carers?; (4) would they participate in the questionnaire survey? Not all carers agreed to participate in the questionnaire study however the response at this telephone interview stage was important and analysed in this study. The researcher telephoned 100 homes to request for a telephone interview in order to establish interest in this study. After locating the appropriate person the study was explained. If the person was willing to have an interview over the telephone, a series of questions (crib sheet) were asked. If the carer was interested in participating in the questionnaire survey (after the phone interview) then their address was checked to ensure correct delivery. Not all carers interested in the questionnaire were able to participate in the telephone interview. This was due to time constraints and the staff not locating the appropriate person to interview due to the general nature of the care home environment being busy. Senior carers or managers were sometimes not able to take the phone call due to this. In these cases, an explanation of the study was given to fulfil ethical considerations and if it was found interesting, the staff member spoken to the questionnaire would be sent to a designated carer.

2.2.3 ii The questionnaire survey

The questionnaire was designed based on research of existing literature, discussions with a Continence nurse specialist and deploying a draft of the questionnaires to two care homes. The questionnaire survey was developed with support from Dr. Christine Shaw a specialist incontinence nurse and members of the HESAS research fraternity who also reviewed versions through to the final one (Appendix 1b). To test the content validity of the questionnaire a draft was posted to two care home carers. Feedback was obtained via telephone. This helped recognised if questions were comfortable to answer, to highlight misinterpretations or to identify any questions that do not work well for the study. Both carers reported that the questionnaire was easy to understand, comfortable to complete and was not very time consuming to fill out. The questions were designed so that they could be answered reasonably quickly by being easy to understand, not ambiguous, it did not influence the carers completing the questionnaires and they were given a fair opportunity to provide honest perceptions. The questions were worded to refer to UI experienced specifically by all dementia residents irrespective of what type of dementia or the severity of the condition. The questionnaire contained thirty questions in total. The structure of the questions varied and incorporated different techniques for answering. Socio-demographic variables were investigated and they consisted of indication of the caring role, years of experience in elderly care, the number of people who had dementia and incontinence among others. It contained open ended questions such as: 'Which skills do you consider as most important to do the job properly?' Further questions were 'What is the reaction of dementia residents when checked or prompted for toileting', 'Do resident's ever return to near or full continence?'. The degree to which certain questions were impacted on the carer was designed as multiple choice or categorical questions with ranking. Some questions were rated on a 4 or 5-point Likert scale, ranging from 1 (least challenging) to 4 (most challenging) or 1 (least important) to 5 (very important). The higher scores indicate more adherences to the principles of care home service delivery (Verbeek, 2012). Several multiple choice questions were administered with the option of commenting further so that if they disagreed with the choices given then opinions to be expressed. Participants were given the option to comment on most of the multiple choice questions, however for seven out of the thirty questions, there were no opportunities for this. These were categorical type questions that were based on a timeline or pre-set choices based on the literature, which were: 'How many years have you worked in this care home? (answers in multiple choice categories of 5 year intervals between 5 years and over 31 years, Appendix1 b). Questions to find out numbers of individuals affected by a phenomenon were also used, these questions included: 'How many residents currently: suffer with dementia and have incontinence', 'How many people with dementia with incontinence use pads or indwelling catheters?' Questions with numerical ratings (for example least important to most important), were assigned to measure the response to certain questions and this also allowed the opportunity for comments. The 'yes' and 'no' questions were also utilised including the opportunity for additional comments. All respondents that did not complete the questionnaire were treated as 'missing', or for unanswered questions a 'no answer' response was recorded. The questionnaire contained three sections (1) Section A: background information on carer and residents; (2) Section B: management of incontinence from the carer's perspective and (3) Section C: product design: ideal solutions for using sensor technology. Each of the sections was identified with further questions. In section A the background was covered as it was necessary to find out the construct of the care home and the role of the carer and experience in the field. The important points needed were the size of the home, the type of home and number of people and whether residents return to continence after being admitted into a care home due to their incontinent status. Section B focused on the care home management for UI to find out the patterns of routine checking by carers, the usage of containment products, to identify behavioural tendencies of residents due to checking and toileting in addition to the challenges faced by carers. In section C, the product design section aimed to engage the carer to contribute ideas on suitable designs of a piece of equipment if sensor detection technology is used in parallel with their current management protocol. It was important to find out what the carers think about existing designs and if there was a desired design type that would enable more acceptance of using technology. Questionnaires were sent out with information sheets and participating guidelines as required by the Faculty Ethics Committee at the University of South Wales (Appendix 1 c). Stamped envelopes were sent out for carers to post the completed surveys by the deadline (3 weeks after the questionnaire would be posted out). Halfway through the 3 week period a follow up telephone call was made to provide support for the carers. If the researcher received no returns by the deadline date, a further phone call would be made to discuss a new completion date (roughly two weeks later).

2.2.3 iii Setting and participants

The homes were found on a database called the carehomes.co.uk (www.carehomes.co.uk, 2012) (Figure 2.1). This study focused on carers from private care homes with dementia facilities in England and Wales (Table 2.2). Table 2.3 displays the sampling techniques used.

Table 2.2: The breakdown of care homes in England and Wales.

Country	Total number of care homes	Residential Homes	Nursing Homes	Private care homes (within the total number of care homes)	The number of private care homes that have dementia care facilities.
England	17 332	12 860	4472	12 919	7649
Wales	1144	853	291	910	310

Key: The management and quality of all care homes in the UK on this website are regulated and governed by bodies that regulate good practise in care homes, hospitals and care services such as the Care Quality Commission in England and Care Standards Inspectorate for Wales (supervisory). At the time of this survey (2012) there were 20,308 care homes in the United Kingdom (England, Wales, Northern Ireland, Scotland, the Channel Islands and the Isle of Man. However this study focuses on private care homes in England (7649 care homes) and Wales (310 care homes) that have dementia care facilities (www.carehomes.co.uk, 2012). Careful considerations had to be made in order to select a sample size that could represent the total population as closely as possible so that resources such as time and money may be utilised effectively (Bartlett, Kotrlik and Higgins, 2001; Thomas, Nelson and Silverman, 2011). The size of the sample is based on how closely the results could match those of the entire population (Marder, 2011). Two measures may be used to determine the accurateness of the data. The margin of error, is the deviations between the opinions of the responders and the opinions of the entire populations and this could be 5%. This means that we are left with a confidence interval of 95% (Thomas, Nelson and Silverman, 2011). Finding the margin or sampling error is important in determining the sample size because it tries to minimise two types of errors which are the alpha or type 1 error (finding the difference that does not actually exist in the population) and the beta or type 2 error (failing to find a difference that actually exists in the population) (Peers, 1996). Once the accuracies are decided then the sample sizes may be computed. For most research the alpha level of 0.05 is acceptable where the t-value is 1.96 for a population of above 120, however the t-value would be 2.00 for a population of 60. The values used should be appropriate to the size of the population. However in order to determine the correct sample size requires complex methods of analysis such as Cochran's (1977) sample size formulas or Krejcie and Morgan's (1970) formula among many other techniques that exist (Bartlett, Kotrlik and Higgins, 2001). The sample size of the categorical data required for both England and Wales (based on the entire population of care homes with dementia care facilities) may be retrieved from a table developed by Bartlett, Kotrilk and Higgins (2001). This table can determine the sample size needed for a given population for categorical data. The total number of care homes with dementia care facilities in England and Wales are 9,959 (Table 2.2) and this would be the number of carers that would be targeted. According to the table developed by Bartlett, Kotrlik and Higgins (2001), for a population size of around 8000, a sample size of 262 would be sufficient for categorical data based on the margin of error appropriate for the study (Appendix 1d) Due to practical reasons, budget and time constraints, the author was forced to use an inadequate sample size of less than half of the suggested size (100 care homes). The focus of the sample size was not to find out if it represented the whole population but acted as a pilot study for the possibility for larger sample sizes in the future. The smaller sample size was deemed adequate by the author for the collection of high quality data and efforts in retrieving more reliable, valid and generalizable results (Bartlett, Kotrlik and Higgins, 2001). Response rates vary and it depends on the sample size of the population studied, however most online surveys receive 26% response rate (Hamilton, 2009). Interviews usually have a higher response rate (77 %), however mail surveys are usually lower (67 %). A response rate as low as 30 % for mail surveys has been viewed as 'reasonable' (Smith, Scammon and Beck, 1995) and really good for online surveys (Schrijver, 2013) whereas 50 % has been seen as 'quite high' (Sapsford and Abbot, 1992), although 80 % response rate is regarded as 'very high' (Hopton, Howie and Porter, 1993). The response rate was suggested to be not related to the questionnaire length (Sitzia and Wood, 1998).

Figure 2.1. Screen shot of selections made on the care home website.

Key: On the 'carehome.co.uk' website, the number of care homes in 'England' or 'Wales' can be found under the 'care homes by country, region or county' category. Selecting a country 'Wales' for example will bring up a page with a list of all the areas that have care homes. The number of care homes in each area is indicated in the brackets for example Cardiff (86), means that there are currently 86 care homes in Cardiff. Further parameters were used to concentrate on dementia care homes in England and Wales: Private Homes-Dementia-Wales (or England). Due to the large number of care homes found, the researcher manually located the first two private care homes that appeared on the list for all the regions in England and Wales that had homes registered on the website. One carer from each home was required to participate.

Table 2.3 Sampling planned and achieved for the study.

Sampling planned	Sampling achieved
Proportion of care homes (Quota sampling)	The study was initially conceived with the idea of comparing attitudes of those working in care homes in England and Wales about use of sensor technology in the care of residents with dementia. This resulted in the contacting of 100 care homes, of which 50 were from England and 50 were from Wales. Although the care homes are almost balanced between the countries, the proportion of those responding private care homes with dementia facilities was not significant balanced to allow a comparative study (England= 96% and Wales= 4%). The denominator for these proportions were the total number of private care homes that have dementia care facilities (relates ti the remit of the author's sampling criteria) (Table 2.2).
Location of care homes (Convenience sampling)	On the 'carehome.co.uk' website (accessed January, 2012)), the number of care homes in 'England' or 'Wales' can be found under the 'care homes by country, region or county' categories. Selecting a country, 'Wales' for example, brought up a page with a list of all the areas that have care homes. The number of care homes in each area is then indicated in the parentheses: for example Cardiff (86), indicating that there are currently 86 care homes in Cardiff. Further parameters were used to hone in more specifically on dementia care homes in England and Wales: e.g., using the term "Private Homes-Dementia-Wales (or England)". Due to the large number of care homes found, the researcher manually located the first two private care homes that appeared on the list for all the regions in England and Wales that had homes registered on the website.
Carers approached (Expert sampling)	Carers regularly dealing with elderly residents who are incontinent and had dementia were considered to be in the best position to inform on current management methods. The lack of direct communication between the dementia residents and carers concerning their continence needs was expected to create a barrier, which would have only increased the burden of care (Brodaty and Donkin, 2009, Brittain and Shaw 2007). The Mental Health Act (2005) allows carers and healthcare staff to carry out very personal care in relation to hygiene and continence management for people who lack the ability to consent, such as dementia sufferers. However, it is often very difficult to investigate or receive feedback about their care from dementia residents directly. People who have both dementia and urinary incontinence tend to be unable to -complete the questionnaires (Shaw et al., 2004) and so it is often suitable to have their carer's involved in the design of anything to help meet clinical requirements (Long et al., 2010). Since dementia sufferers will inevitably experience urinary incontinence, this coupled with the behavioural changes associated with dementia could ultimately provoke challenges in the management of UI (Lievesley, Crosby and Bowman, 2011). Therefore, for this study, one carer from each care home in the target population group made up the sample for this study.
Type of care homes (Purposive sampling)	Private owned care homes are more accessible for interviews because there is a considerable degree of autonomy and are more able to make decisions about participation with research. Homes run by larger groups such as the NHS may not have this degree of accessibility. The majority of care homes in the UK are run by the private or the commercial sector (73%) (Enrich, 2013). Some homes are run by the voluntary sector (14%) or owned by the local authority (11%). Small percentages (2 %) are supported by the NHS (Enrich, 2013). Privately owned care homes tend to be run either by an owner manager (as in a family business) or as part of a national or internal chain which have shareholders. There are also some privately run care homes which are owned by charities (Enrich, 2013). All the care homes approached in this study were privately owned and so the owner managers or the appointed managers were accessible at the telephone interview stage. As mentioned above, owner managers experience a considerable degree of autonomy and so were able to make decisions about engagement with research opportunities, such as this one. It was considered to be too difficult to approach care homes that are run by large groups such as a local authority or the NHS because of the inevitable delay in decision making process and the possible misinterpretation of the aims (they may not be able to make decisions about getting involved with research without referring to the requests to their Head Office which may take some time (Enrich, 2013)).

Key: This table displays the sampling techniques used to sample the data appropriate for this study.

2.2.4 Data analysis

The questionnaire was semi quantitative containing qualitative and quantitative aspects. Data was processed using Microsoft Office Excel 2007. For the qualitative aspect of the data, questions were recorded on an excel spreadsheet. The answers were manually typed into the datasheet by the author. Each question (open ended questions and comments from multiple choice questions) was assigned to the top of individual column which were numerically identified according to the sequence in the questionnaire survey. In addition the location of response, either England or Wales were added for reference. Descriptions or quotes presented in the results were taken directly from the questionnaire as verbatim, however care was taken to correct the grammar and tense so that it would be accurate when read in context. The answers were then analysed according to the questions asked: the differences or similarities were compiled. The same was performed for the responses to the quantitative questions that were categorical, ranked and multiple-choice. These categories and ranks were assigned beneath their associated questions and the responses by carers were manually inputted and verified. A similar process was completed for the multiple choice answers. For numerical data, simple descriptive statistical analysis was performed producing means and standard deviations. Data verification (checking the electronic against the original data) was completed for both quantitative and qualitative responses. Additionally, further random checks were made to ensure the responses matched the questions in the correct column on the excel sheet when compared to the questionnaire hardcopy. The units of textual data from comments included words, sentences or paragraphs. Based on the layout of the data, key themes and patterns were searched for. Following this, relationships and connections between categories were explored against data. Analyses were deductive in which were followed current literature and theory on the concept and philosophy of care home management (Verbeek etal, 2012).

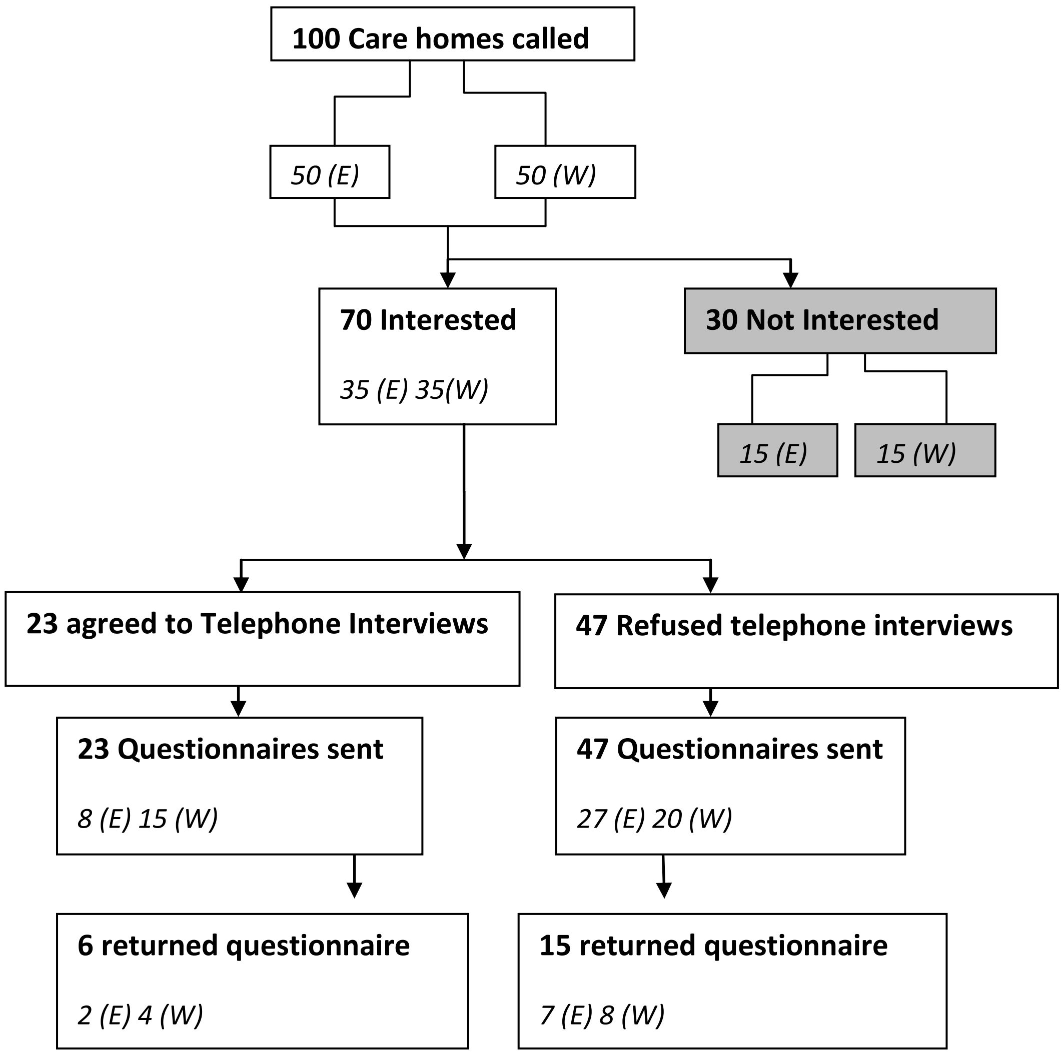
2.3 Results

The results presented are the outcomes of a mixed methods approach applying two methods namely the verbal telephone and written questionnaire survey. As explained earlier the telephone survey had four themed questions to introduce the idea of the research to respondents, whereas the questionnaire then went on to deal with the wider related issues relevant to this research. The results presented here bring together ideas that are generated from both the telephone and questionnaire survey. This will then be followed by the discussion and conclusions that will be drawn to address the original research objective and aims (Table 1.1). The scope of response is on figure 2.2. The information is broken down into the number of participants from England noted as '(E)' and Wales noted as '(W)'. Table 2.4 shows the response rate of the questionnaire in relation to size of care home (number of beds). This section refers to the management issues addressed in both the telephone and questionnaire survey.

2.3.1 Management methods and issues: Telephone survey

The results of the telephone survey show that of the 23 homes that were called, 52 % (12 homes) admitted problems with managing incontinence in dementia residents and 48% (11 homes) reported that their incontinent dementia residents were managed well. All homes reported having a monitoring program for each resident for managing their incontinence (so that pad allocation and toileting prompts may be identified), although one home commented that, 'residents are still incontinent even with this programme'**.** The main reasons reported as to why this may happen include, 'lack of cognition' (of patient), "residents can hide incontinence episodes to avoid loss of dignity' or 'they are unable to communicate' as well as 'they might not cooperate or don't want to be checked". Only one respondent offered the comment that due to the busy nature of their care homes and frequent changes in care staff, as well as the safety of the resident, they considered the routine timed checks is the best method for consistent management. All homes from the telephone survey reported that residents who are incontinent are checked every 2 hours in the day time although in the night the frequency can be reduced to every 4 hours. All homes also reported that night time management is more challenging than day time.

Figure 2.2. Breakdown of telephone and questionnaire survey samples



Key: A total of 100 care homes were contacted in England (50) and Wales (50) via telephone and one carer from each home was asked if they would be interested in participating in a short telephone interview followed by a questionnaire survey (T & Q study). Seventy homes agreed to participate in this study (35 homes in England and 35 homes in Wales). In general out of the 35 homes in England (interested in the study) there were 28 nursing homes, 7 residential (combined with nursing facilities). Of the 9 in England that responded, 7 were nursing and 2 residential homes. Out of the 35 homes in Wales, there were 16 nursing homes and 19 residential homes. Of the 12 that responded in Wales, 8 were nursing homes and 4 residential homes. However only 22 % (23) of these 70 homes agreed to have a telephone interview and a questionnaire survey sent to them (T & Q study). Although the remaining 47 homes were unable to participate in the telephone interview (due to time constraints and caring commitments they had just asked for a questionnaire survey to be sent out (Q study). Of the 23 homes that were interviewed via telephone, only 6 homes completed and returned questionnaires, consequently of the 47 homes that only participated in the questionnaire survey, only 15 had completed and returned the questionnaires. In total 21 homes (out of 70) completed and returned the questionnaire (30 % response rate). The 100 homes were located all over England and Wales and there was no outstanding relationship with the responders and location that they came from and this followed through with the questionnaire participants (70) including the 21 questionnaires returned. To help to broaden the scope of data the triangulation method which is one of the quality procedures in naturalistic inquiry was used to analyse the data in the questionnaire (Greene et al, 2005). The triangulation method measures the same concept using two or more methods that can analyse both quantitative (validation) and qualitative (inquiry) studies in order to investigate the convergence of the results within the questionnaire (Thomas, Nelson and Silverman, 2011). During the follow up period after questionnaires were sent out, contacting the managers for updates were also straightforward. This meant that the researcher was also able to provide direct support to the care managers or carers who were responding to the questionnaire.

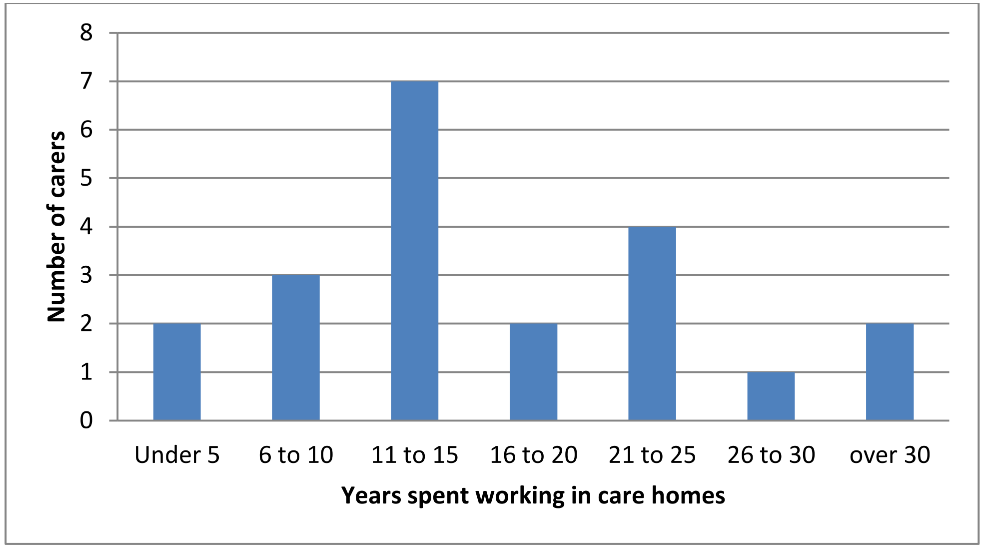
Table 2.4: Size of care homes

	Numbers of beds			
Location of responders versus non-responders	**0 to 50 n=58 (E =23 W =35)**	**50 to 100 N= 34 (E=21 W=13)**	**100 to 200 N=8 (E=6 W=2)**	**Total homes N=100 (E=50 W=50)**
England Responders	6 (26%)	1 (5%)	2 (33%)	9(18%)
Wales Responders	9(26%)	3(23%)	0	12(24%)
Total	**15**(26%)	**4**(12%)	**2**(25%)	**21**(21%)

Key: n = number of samples; E = England; W= Wales.

This table shows the breakdown of responders in England (9 homes) and Wales (12 homes) in relation to their respective bed size. Most of the respondents from England were from homes with less than 50 beds (6 homes). In Wales, most of the respondents were also from homes with less than 50 beds (9 homes). It appears that the smaller the homes the better the response.

Figure 2.3. Number of year's respondents had spent working in care homes



The questionnaire allowed comparison between the perceptions of carers, nurses and managers based on length of service. From the perspectives of this study, the element of length of service can be used as a potential exclusion criterion, if their views differ significantly from those with lengthy experience. However, this determination will be made post-hoc. Of the 21 questionnaires returned, 90% of the participants were care managers (19) and the rest were nurses (1) or a unit/team leader (1).

It was reported that there is more aggravated behaviour generated by disturbing residents in the night time (12 homes) because of the confusion and distress. If there is no need for a change at the time the resident is checked, the stress of the checking might cause residents to pass urine just after a routine check (5 homes) and this may not be known until the following check causing the resident to be in an uncomfortable state (4 homes) and therefore most likely more stressed. The passing of urine between checks causes restlessness in patients (5 homes), and additionally, it is difficult to get residents back to sleep after they have been checked or changed (12 homes). One home commented that "occasionally accidents at night time are a problem and it disturbs sleep. However, embarrassed people can get restless and fidgety and carers may use this as an indicator that the person needs to go to the toilet". According to the results of the telephone survey, the main methods used by all the homes were the use of containment products such as pads or commodes (all homes), toileting programs (all homes) and in some cases catheterisation (5 out of 23 homes).

2.3.2 Management methods and issues: Questionnaire survey

Collectively within the 21 homes out of a total of 916 residents, 610 people reported to have dementia and of this population, 403 people had dementia who also suffered from UI. This equates to 66 % of this total population of people with dementia who also were reported to have UI. From the results of the questionnaire survey the main methods used for managing incontinence for all homes were reported to be the usage of incontinence pads, toileting programmes and catheterisation. The information clearly confirms the telephone interview data. Routine pad checks are carried out at different timed intervals decided by each care home. Four care homes reported to occasionally check the residents between the routine checks in case of soiling although one home reported that they rarely do this and only abide by the timetabled checks due to the busy working environment. The rest of the homes reported that they frequently check between routine scheduled checks and this is simply carried out upon observation on passing the resident. As shown in Figure 2.3, 62% of these participants had spent a large amount of time between 10 and 25 years in the care home industry.

2.3.2 i Incontinence pads

Pads are used for urine containment as part of management in all homes that participated in the questionnaire survey. It was reported by one home that it was usual practise to use containment products alongside toileting programmes for most residents (unless immobile). The carer concluded that checking and changing of pads appears to make up a large proportion of their role. Incontinence pads were reported to be checked more often in the day time (maximum 5 times) than the night time (maximum 3 times). Checking is reduced in the night time to avoid sleep disturbance, however because of this containment products can be used more (1 home reported). From the questionnaire results, it was reported that 67 % (14 homes) of the homes check on their residents more than 4 times in the day which is about every three hours or less. In the night time 76 % of the homes check between 3 to 4 times and more than 4 times roughly equating to checks being made every 4 hours or less. Most homes allocate between 2-4 pads per resident although 1 home allocated 6 pads. Allocation depends on the needs of the resident (from assessment). It appears that the pad use exceeds these allocated numbers (reported by 8 homes). All homes reported that pads are changed if they are wet and saturated but not if they are dry. One home in particular changed pads at every check. Eight homes reported that allocation of pads was based on the individual needs which are derived from the assessment of the resident by a specialist nurse. Although these same 8 homes further stated that they used "*as many pads that are needed*", suggesting that allocated numbers may not be sufficient. The data in Table 2.5 show the allocated pads compared to the pads that are used by each home per resident per day. Incontinence pads in care homes are supplied by the local councils (NHS funding) and each patient is allocated a specific number of pads per day (including night). The pad allocation per resident per day is dependent on the needs of the individual which is assessed by a continence nurse (Alzheimer's Society, 2013). These pads provided by the local councils are usually large, bulky and very uncomfortable to wear. If they are unsuitable for the wearer then there are no alternative provided publicly. The individual or their family have no choice but to pay privately, if they can, for a better alternative. If they cannot afford an alternative the only option is to make do with the uncomfortable pads (Alzheimer's Society, 2014). One home stated that pads provided by the local council that are not the best product and may cause skin irritation and may not be of adequate absorbent capacity. This home puts up with this although they wish that the product could be better.

2.3.2 ii Toileting

All homes reported that individualised programmes are recorded on "continence charts" to calculate frequencies for toilet visits. Of the 21 homes, 2 homes reported that they toilet residents at intervals of between 30 to 90 minutes in the day time. The rest of the homes toilet patients at between 2 and 4 hourly intervals during the day. Almost 50% (10) of the homes commented that residents are resistant to regular toileting during the night.

Table 2.5: Allocation versus used pads: data from each care home

Care home location	Size of home (number of residents)	Pads allocated (by care homes) per resident per day?	Pads used per resident per day?
England	22	2-4	4-5
England	28	3	up to 5
England	114	4	up to 8
England	119	4	up to 6-8
England	43	4 to 6	6
England	120	Varied according to needs.	Varied according needs.
England	39	Varied according to needs.	Varied according needs.
England	76	Varied according to needs.	4
England	32	Varied according to needs.	4-6
Wales	22	No response given	3-4
Wales	71	3	3+
Wales	19	3-4	Same as allocated.
Wales	6	4	4-5
Wales	64	4	6+
Wales	27	4	5-7
Wales	36	5	4
Wales	22	6- depending on severity	6
Wales	12	Varied according to needs.	Varied according to needs.
Wales	37	Varied according to needs.	Varied according needs.

Key: According to the data collected from the questionnaire all homes use more than is allocated to them. In particular, the larger homes sometimes use up to double the number of allocated pads per resident per day. One home mentioned that they used the same amount as allocated although it was a home with 19 residents.

2.3.2 iii Catheterisation

Catheterisation was reported to be used by 10 homes (from the questionnaire study) of which 6 homes have 1 resident each on a catheter (home size: 21- 40 full time residents), and 4 homes have between 2 and 5 residents who are catheterised (home size: 26 - 120 full time residents). Catheterisation is reported to be carried out by one home, "on residents who have returned from hospital, have prostate problems or if they are heavily incontinent". A catheter is inserted through the urinary system and into the bladder for continuous dispelling of urine (Getliffe and Dolman, 2007). One home stated that catheterisation is routinely used within their care home: *'residents are normally catheterised if they are prone to leaks and accidents'.*

2.3.2 iv Return to continence

When the carers in the questionnaire study were asked if the incontinence dementia residents ever returned to full or near continence, 61 % (13 homes) of the carers reported that this would never be achieved and the reason for this was highlighted by one home as due mainly to the cognition of the individual. Twenty nine percent (6 homes) of the carers reported that it was possible to achieve near or full continence occasionally, although 4 homes within this number mentioned that this should be carried out with support from carer workers. The remaining 2 homes did not comment.

2.3.2 v Investigation of related tasks

From investigations in literature the questionnaire study focuses on four broad tasks associated with caring for dementia residents as: feeding, handling behaviour (how carers cope with the interactions of residents and the emotional impact residents have on carers), incontinence (pad checking and changes, toilet prompts) and personal care (bathing and basic hygiene) (Alzheimer's Society, 2014; NHS Choices, 2013; Price, 2011; Banerjee et al., 2012). Communication is another task that is involved in the caring role however in this case it will be included in category of' behaviour' this is because people with dementia seem to be more expressive in behaviour if their verbal communication skills may be diminishing due to the neurological condition (Table 2.6). Each carer was asked to rate all four tasks (feeding, behaviours, incontinence and personal care) as the most time consuming tasks (defined as challenging) associated with managing residents with dementia in the order of 1, 2, 3 and 4 (1 being least challenging and 4 most challenging) . Some of the comments from the questionnaire were made relating to the tasks on feeding and behaviour may be seen on Table 2.7.

Table 2.6: Collected ratings for the selected task areas.

	Number of carers that gave the ratings			
Rating	**Feeding**	**Behaviour**	**Incontinence**	**Personal Care**
1	9	0	1	5
2	2	5	9	4
3	4	4	6	4
4	4	10	3	6
Mode of ratings	1	4	2	1/4

Key: Nineteen homes gave ratings; of the remaining 2 homes, one commented that the challenges '*varied between patients*' across the task areas, and the other stated that *'it was very difficult to rate as all residents have individually different levels of challenging tasks'*. Under the 'feeding' category, nine homes rated it as least challenging '1' (highest mode rating) than any of the other categories although, four homes rated feeding as most challenging '4'. This may have a relationship to the results of the next task 'behaviour' of which 10 homes had rated this to be the most challenging task. Most homes scored the task of managing 'incontinence' closer towards a least challenging task (mode of 2). The rating for 'personal care' however had a mode of most and least challenging.

Table 2.7: Comments relating to the tasks feeding and behaviour.

Comments Relating to:	Comments	N=number of homes
Feeding	*'most residents appear to love their food'*	1
	'that some residents may take up to an hour to assist due to swallowing or with cognitive issues'	1
	'need prompting to eat and drink and behaviour of resident during the feeding task may fluctuate'	1
Behaviour	*'mood, psychological disturbances, disinhibited behaviours are all factors that increase time required as well as moving and handling safely'*	1
	'resistance, dignity and privacy compromise'	1

2.3.3 Perceptions of using sensor technology

This section refers to the perceptions of carers in using sensor technology for managing incontinence which were explored in both the telephone and questionnaire survey.

2.3.3 i Telephone survey: Views of carers on using sensor technology

From the telephone survey 11 homes out of 23 reported to be satisfied with their management of incontinence. However when asked about their opinions on using sensor technology to assist with management, different views were reported (Tables 2.8 and 2.9). Perceptions of using sensor technology in line with management included "sensor technology would give false detections" which could lead to "the increased need for carer support if detections were not accurate". This has been reported to potentially "slow down management". It was reported that the "confidentiality of patients may be at risk" because the status of the individuals incontinence may be publicly known. The general perception for this group was that carers prefer manually checking the residents routinely. All homes also commented that "carers preferred pad usage" to manage their incontinent residents. Interestingly they also stated that "it (sensor detection technology) would be better for less communicative people where they are unable to notify staff if they need the toilet". Of the group of carers who said no (Table 2.8) to technology, only four responded to the job status and time working in care homes question. Two were managers who had worked between 11 and 15 years, one manager had worked between 16 and 20 years and one had worked 21 to 25 years in care homes. From the telephone survey, of the group of carers who said yes to technology (Table 2.9) twelve responded to the job status and time working in care homes. One manager had worked 6 to 10 years, five were managers who had worked between 11 and 15 years, one manager and two carers had worked between 16 and 20 years, one manager had worked 21 to 25 years, one manager 26 – 30 years, and finally one manager had worked more than 30 years in the care homes. Of the 12 homes that considered incontinence management to be a challenge, all homes reported in the context of sensor technology that (as shown in Table 2.9), "it would be a good way to report missed incidences between checks" as well as "to avoid night time disturbances." It was further reported that "sensor technology could indicate immediate wetness" which could 'encourage immediate action. In addition it "would be good for less communicative people" who may not have realised they have wet themselves. This could create an environment where the needs of residents are respected and valued when help is required, essentially maintaining their dignity.

Table 2.8: Perspectives on using sensor technology from Carers who disagreed with the need to use technological solutions.

reasons given to support the contention that there was no need for a technological solution:	**Number of carers (total n = 11)**
Managed well'	2
Slows down management/ carer dependence'	2
Not necessary for residents with better cognition'	2
Cost barrier'	1
Prefer traditional checks carried out by carers'	1
Carers may depend on it too much/misuse by staff	**1**
Sensor technology might give false detections	**1**
Confidentiality of patients may be at risk	**1**

Table 2.9: Perspectives on using sensor technology from Carers who agreed with the need to use technological solutions.

reasons given to support the contention that there was a need for a technological solution	**number of carers (Total n=12)**
Maintains dignity of resident'	2
Avoid night time disturbances'	8
To report missed incidences'	2
Good for residents who cannot communicate'	1
Encourages immediate action'	2
Total number of responses	**15**

Key : None of carers in this group had ever used detection technology to help with management of incontinence; however, 20 homes considered that it could be useful if they were provided with more information.

2.3.3 ii Questionnaire survey: Views of carers on using sensor technology

When carers were asked if sensor technology would help to manage incontinence in dementia residents the results progressed from the telephone survey. Of the 21 returned questionnaires 71 % of the carers (15 homes) agreed (said 'Yes') that sensor technology may benefit as shown in Table 2.10. The results show some comments made by the carers. Those agreeing with sensor technology suggested that it could reduce the incidence of incontinence by identifying urine patterns and thus maintaining the dignity of residents, which could ultimately save time in management. However 5 homes reported that sensor technology would not benefit because all residents already have individual care, are regularly checked and such a product would be more useful in the hospital setting although this was not elaborated. One home said that that they were, "unable to comment until it (sensor detection technology) was seen in practice".

2.3.3 iii Desired design of sensor technology: solution to detecting UI

All homes are exposed to technology in the form of nursing call systems and 52 % of the homes (11 homes) use pressure mats to detect movement of residents. Table 2.11 shows the desired design criteria of the carers for a sensor detection system. Carers were asked to rate which design idea would be most important if they were to use a sensor detection system to monitor incontinence in dementia residents. The results in Table 2.11 show the percentage of carers who rated the design ideas from a scale of between 1 very important and 5 not important. The author made a judgement between the ratings for very important (1 and 2) and not important (4 and 5) in order to summarise the general response. The middle value 3 was perceived by the author as a neutral and was not taken into account. Not all the carers answered this section and the total that did is listed below so that the percentages can be appreciated. As shown in Table 2.9 an ideal system sensor detection system for an incontinent dementia resident would be one that is embedded in the bed rather than on the person's clothes (58 % of the 12 carers who answered felt this way). A wireless system is slightly more desirable probably due to the portability nature (56% of the 16 carers answered this). Carers seem to not like the idea of alerting incontinence to a central computer system (82 % 0f the 11 carers who answered) although there was only a 50% (of 16 carers that answered) acceptance in having alerts through to a mobile phone device. When it came to bedside alarms, 67 % of the carers did not want this and alerting discretely is reported to be preferred (64 % of 17 carers who answered). A battery powered system is also a favoured option.

Table 2.10: Perceptions of carers on using sensor technology for management

	Could sensor technology aid carers in managing incontinent dementia residents?	
	Yes	No
Number of carers	15	5
Reason (with number of carers who commented in the brackets)	• Reduce incidence of incontinence (1) • Identify patterns for passing urine (1) • Enhance dignity of residents (3) • Tend to residents quicker (3) • More discrete for resident (1)	• Residents regularly checked, prefers this traditional approach (3) • Individual care is already provided - suitable for hospital use (2)

Table 2.11: Design criteria for a sensor monitoring system.

Desired design criteria of carers for a sensor monitoring system for detecting incontinence in people with dementia.	Total number of carers answered	Number of carers, reported decision:	
		Important (%)	Not important (%)
Sensors in bed	12	58	
Sensors in clothes	13		62
Sensors that are wireless	16	56	
Alert carers : Mobile phone	16	50	
Alert carers : Central Monitor	11		82
Bedside alert: Alarms	12		67
Bedside alert: Discrete system	17	64	
Using mains power	13	54	
Using battery	13	69	

2.4 Discussion

A visit to a dementia care home (page v) along with the interviews inspired the author to design the studies in the following chapters. It was considered vital to engage the carers with the potential design and use of technology, since they are in direct line of care with people with dementia. Therefore, the inclusion criteria for this study were being a carer (with a direct caring role of dementia) and working in a private care home in England or Wales. The exclusion criteria included any carers working predominantly with incontinence as the result of conditions other than dementia and carers without experience. This descriptive cross-sectional study utilised two methods for collecting data namely the telephone interviews and a questionnaire survey. The telephone interviews were carried out by calling the homes and determining if there was any interest of involvement in this study. Consent was based on the willingness of the carers to speak to the interviewer. As there was no formal consent at the telephone interview stage, out of respect, the interviewer requested permission of the carer to use any appropriate data from conversation. At this stage the names of the interviewees were requested and if they were agreeable, questionnaires were sent to these people. This was because the telephone interview aimed to provide the person with an introduction to the research idea and any clarification on the study could be carried out at that point. Regarding reasons for lack of completion, the most common was not receiving forms or losing them. In these cases, the interviewer posted out new forms, although this was only carried out once for every home. This was performed in order to improve response rates; however, a more effective technique would have been direct engagement of carers with the interviewer using focus groups or one-to-one interviews. The strength in using interviews is that they bring richness in the data, portraying feelings, experiences and distinct perspectives of carers (Verbeek et al., 2012). The responders were informed that completing and returning the questionnaire implied consent to use their responses and data; however they were assured that their anonymity would be strictly adhered to. The interviewer ensured that all information collected about each care home studied would be kept strictly confidential and would not be used for other studies (in keeping with the requirements for ethical approval). Names of the carers were removed from the results so that they could not be identified, however it was still possible for the homes to be identified. This was considered important as it allowed for issues relating to misconduct or malpractice to be communicated back to the care home if such information was declared in the questionnaire. Limitations emerged in the research process, for example the same questionnaires were administered and assessed for both smaller and larger care homes, however, whether all experiences are similar or specific to the size of home has not been ascertained. Further, only one carer per home was investigated to gain an in depth insight of experiences. While these aspects could be limiting for the findings, it must also be acknowledged that the mixed methods study approach broadened the scope and validity of this study by combining data from the questionnaire with the interviews. This approach would be useful to improve the likelihood that opinions presented in the telephone interviewers could be examined with regard to the answers in the questionnaire and to explore the issues in greater detail (Verbeek, 2012). To maximise the impact of this study, it would be appropriate for the information gathered to be disseminated to the all the homes that participated. This would be a positive step to take to ensure that the carers are able to appreciate that their views are taken into consideration. The author decided to speak with carers with a greater period of experience because; it was assumed that they would be able to provide more indepth feedback on the care environment as well as the methods currently used (Williamson et al., 2009). The author was only able to target 100 carers due to time constraints (Shah et al., 2010). In order to reach out to a wider group, an additional 30 care homes in England and Wales were contacted, however these carers were not interested in either the telephone interview or the questionnaire survey. It was challenging to speak with some carers who assumed the call to be for 'sales' purposes. It was hard to accurately measure how generalizable the findings of the data might be. Discussion with carers, managers and continence nurses at the telephone survey stage have shown overlap in their views, therefore it was anticipated that qualitative elements should reach saturation easily with small numbers of carers (around 10 carers, an assumption made by the author) and as suggested in the literature (Lincoln and Guba, 1985). One clear example of the data saturation reached in this study was during the main methods used to manage UI which were the use of containment products (pads, commodes) and toileting prompts. People with dementia with urinary symptoms may be unable to self-complete the questionnaires (Shaw et al., 2004). Therefore it was suitable for carers to propose suitable design ideas that could meet the users as well as clinical requirements (Long et al., 2010). Carers are in a unique position to provide guidance for technology development by articulating the needs of their resident's and the providers. However it has been reported in the literature of earlier research that their input is limited (Kang et al., 2010). There have been many trials and techniques to demonstrate improvements in management of continence although more research needs to be done beyond the experimental stage or an unproven technique (Price, 2011). The questionnaire in the author's study allowed involvement of the carer in the design phase thus allowing the carer to feel more involved with the function of a suitable system, making them feel more positive about technology. It is desirable to consider the perceptions and design ideas of the carers who are in the front line of care, and the key aspects of these findings from the perspective of the carers provide the main contribution to this research.

2.4.1 Management methods and issues

Earlier research has suggested that the prevalence of UI in care homes still remains high despite multiple years of improvement through clinical efforts and research (Palmer, 2008). Dementia is associated with long hours of high levels of care which can be physically demanding on the carer (Brodaty, 2009). It has been reported in many studies that carers who look after people with dementia have higher levels of burden than people with physical disabilities (Gonzalez-Salvador et. al., 1999; Ory et al., 1999). Incontinence is reportedly distressing to the caregivers as equally as the person with dementia ultimately leading to care home admissions (Biswas et al., 2008). Carers find coping with incontinence physically demanding and exhausting when associated with the behavioural challenges (Upton and reed, 2005). It is also noted that tasks such as checking, changing and toileting dementia residents take up the majority of the job role (RCN, 2011). People with dementia, unable to comprehend and communicate effectively, may get agitated or emotional during routine checks, which can be invasive (Getliffe and Dolman, 2007; Leung et al., 2008) or as the result of simply being wet from UI. The cognitive impairment present in people with dementia may affect management of UI due to reduced co-operation, therefore it is important that care is tailored to suit the individuals (Hagglund, 2010).

The lack of communication between the person with dementia (when incontinent) and carers may create a barrier between them thus increasing the burden of care essentially causing the carers to work on their own (Brodaty et. al., 2009, Brittain et al., 2007). Nurses usually lead in continence promotion and management. Ultimately it is the responsibility of the nurse to assess the residents correctly and to assess goals and refer appropriately (Price, 2011). Lack of communication because of cognitive impairment might restrain the patient from getting the correct treatment and also their decrease in mobility may also place restrictions on the treatments chosen. Limited information and communication could cause the dementia person to be in receipt of substandard care (Rayner et al, 2006; Benson, 2003; Price, 2011). Dignity is an important value to uphold by a carer as it is concerned with the behaviour of dementia suffers in relation to how dementia residents feel (RCN, 2008). To treat someone with dignity means to treat them in a way that allows them to feel self-worth and respected. In a care home environment, dignity could be either promoted or diminished based on the physical environment, organisation of care culture, the attitudes and behaviour of caring staff. The loss of dignity in individuals (with lack of cognition) could trigger a behavioural response such as lack of confidence, humiliation and shame (RCN, 2008). High staff turnover rate in care homes mean that new carers would take time to get to know the residents which may cause caring discrepancies (Ross, 2011). The repercussion of the higher levels of burden is the currently unacceptable variations reported in the quality of formal care provided by carers to people with dementia in care homes (Zimmerman et al., 2005). While there are many examples of excellent quality of care, there are often reports about formal care not being focussed on meeting the people's needs and aspirations, and thus failing to treat people with dignity and respect (Alzheimer's Society, 2014). The main reason for the high staff turn-over rate and shortages is the difficulty in staff recruitment, and new carers often lack the appropriate skill and subsequently would have to learn on the job. Some of these people have not had experience working within a care home environment and unfortunately care homes do not cater for ongoing training in the basic elements of care such as manual handling, dementia awareness and infection control. They would have to rely on training provided by nurses in charge who themselves find it difficult to allocated time to provide training and support due to the already busy and pressurised care home environments (RCN, 2011). Care homes employ a limited number of contracted staff, and many flexible staff. This is done to save money because flexible carers only get paid minimum wage.

This is currently £6.08 for workers aged 21 and over and £4.98 for workers aged between 18-20 (Directgov, 2011). The low wages associated with carers is not perceived to reflect their responsibilities and is the main reason for difficulty in recruitment and retention of care staff in care homes. This means that residents are not cared by the same staff all the time and less than adequate care may potentially be given due to staff not being aware of recent issues and concerns. Morale is also linked to the quality of care delivered by the carers however with the amount of burden highlighted it is likely that morale may deteriorate. This has worrying implications for the quality of care staff can deliver, and would result in the further reduction of the workforce as more staff leave, further compounding existing problems (RCN, 2011). The low wage will only attract poorer skilled staff which could bring down the level of care brining further problems to the home and more expenses. By increasing pay in staff who are skilled and trained and investing in good quality methods of management that work the care homes may experience less problems (RCN, 2011). Without carers people with dementia would experience poorer quality of life and will be affected by greater expense on the UK economy (Brodaty, 2009). The general role of carers when caring for a dementia sufferer includes a wide variation of integrated tasks such as organising activities to the preparation of food and other household work (Rabig, 2006). Personal care provided by carers include, helping the person with everyday tasks, such as getting washed or dressed, feeding, dealing with challenging behaviour and almost always the management of incontinence (Alzheimer's Society, 2014; NHS Choices 2013; Price, 2011; Grant et al 2014). Carers may feel stressed when trying to communicate to a dementia resident the need to toilet (Price, 2011). Carers find coping with incontinence physically demanding and exhausting if associated with behavioural challenges that come with people with dementia (Upton and reed, 2005). Older people have the highest known prevalence of UI, with the exception of those with neurological dysfunctions and spinal cord injury. The elderly may be more susceptible to physiological, pharmacological and psychological risk factors which may influence their ability to remain continent (Getliffe and Dolman, 2007). Incontinence may be challenging to manage because urinary dysfunction may cause the voiding patterns to vary. The high prevalence of dementia in care homes precludes many from participating in behavioural therapies which include pelvic muscle exercises, biofeedback and bladder training. These interventions are effective among older people however in people with dementia they lack the cognitive function for learning and remembering techniques (Burns et al., 1994).

The presence of cognitive impairment may affect the management of UI because of the lack of co-operation (Hagglund, 2010). Incontinence typically accompanies cognitive impairment and frequently appears in the mid to late stage of dementia (Biswas et al., 2008). It has been reported that the elderly have a decreased sensation of thirst, so by the time they actually drink, they may be already dehydrated which in turn reduces the sensation of a full bladder causing incontinence (Miller, 2008, Price, 2011). Therefore carers have to remind people with dementia to eat and drink to maintain hydration and allow for a more controlled elimination (Price, 2011). In order to ensure people with dementia are able to go to the toilet they would need constant reminders from the carers to establish a regular toileting routine thus reducing the risk of accidental micturition (Ouldred and Bryant, 2008; Price, 2011). While many pharmacological interventions for UI exist there are only few that address functional incontinence (Price, 2011). These interventions are suggested to be beneficial for older people because of the few systemic effects in relation to the positive bladder effects (Smith and Ouslander, 2000; Price, 2011). However dementia residents with functional incontinence would have to use behavioural techniques to combat their incontinence, such as toileting regimes, because the problem is not a mechanical one which may be controlled using drugs (Price, 2011). It can be challenging to keep track of the variations of management and experiences of carers and sufferers especially because there are many different sized homes. Whilst there is not a lot of research on large scale care homes, limited research has been conducted relating to the experiences with the daily care processes in small care home facilities (Rabig, 2006). It has been reported that smaller sized care homes (maximum 8 residents per house) have a more efficient strategy to reduce the care burden (Colvez et al., 2002: Moise et al., 2004; Verbeek et al., 2010). Carers can provide personal attention and additional time to the residents emphasising on the autonomy of daily life (Verbeek 2012). The barriers that were found were that there was the increase of staff shortage in smaller homes. Regardless of the size of the home proper management of functional and physiological incontinence would help to decreases the incidence and lessen the discomfort and embarrassment that surrounds the problem experienced by all care homes. However dealing with patients with dementia would create difficulties when managing incontinence and there is little literature highlighting best evidence based practise when combining these two long term illnesses as more research needs to be performed (Hagglund, 2010). Best methods of management include, assessing the residents for their continence status so that their care may be suitably organised enabling tailoring the needs for specific pharmacological interventions, behavioural techniques, and suitable usage of pads and minimisation of functional barriers to reduce the incidence of incontinence (Price, 2011). Normal patterns of micturition may be difficult to define usually because the majority of studies reported have been done on patients attending clinical for urinary dysfunction (Getliffe and Dolman, 2007). Although individual habits may vary, most adults void every 3 to 5 hours during the day time and not usually at night (some degree of nocturia is accepted as normal). The bladder capacity of the adult is approximately 500 ml and when the bladder empties there is no residual urine left. It has been reported that females void at a pressure of 30 to 40 cmH_2O with a maximum flow rate of 40 to 50 ml/s and males void at a pressure of 40 to 50 cmH_2O with a maximum flow rate of 30 to 40 ml/s (Getliffe and Dolman, 2007). In parallel to the wet checks, toileting prompts are made by carers by simply asking resident's if they needed to toilet (Ouslander et al., 1995). Management techniques for incontinence need to be developed to ensure that dementia patients receive the best care as current methods such as behavioural techniques for incontinence may not be appropriate for people with limited cognitive function (Price, 2011). Assessing people with dementia for their toileting routine requires closed questions and short sentence by carers to minimise confusion when trying to retrieve information (Rayner et al, 2006; Barnett, 2000; Benson, 2003 (Price, 2011). Residents with dementia however may not be able to track their toileting patterns and are usually dependant on carers to record this information for them (Price, 2011). They may also not realise that they have urinated until their pad gets changed an hour later, which would defeat the point of recording correctly to anticipate toileting. However an individualised and comprehensive care strategy that aims to reduce incontinence by regular toileting, pad changes and increases in fibre and fluid intake would make an improvement to a person's continence (Tanaka et al., 2009). Increasing fibre and fluid in-take is important in decreasing episodes of UI (Newman 2007; Bliss and Norton, 2010). Use of incontinence pads and toileting programmes were the most prevalent forms of management and features in many document policies (Roe, 2010). In cognitively able individuals, the residents usually report toileting patterns and then a regular toileting regime is created pre-empting micturition (Morgan et al., 2008; Price, 2011). Toileting programme techniques are widely used and works well at minimising incontinence although it they can be labour intensive (Mathur et al., 2010). Detailed assessment of the toileting problems is crucial in people with dementia, however the difficulties with communication may make this difficult (Singh, 2009; Norton, 2011). Managing incontinence in patients with dementia would be easier if communication is improved (Price, 2011). Research has shown that using technology to monitor the health of dementia residents in care homes have been reported to help by allowing a better night's sleep, less anxiety, improved relationship and positive outcomes or autonomy for person cared for (Jarrold and Yeandle, 2009). The resident may be unaware that they need to be checked, changed or need the toilet and it is due to this sensor detection technology may be of benefit to inform carers on the incontinence status of the resident. Sensor detection technology that notifies when UI has occurred may reduce unnecessary visits and pads checks and allow immediate action (Palmer, 2008). It has been estimated that the time for carer checking on soiled pads can be reduced by 50% through the use of an automated detection system (Biswas et al., 2008). A trigger or alarm system used to raise an alert has allowed carers to reduce unnecessary checking respecting dignity and to ensure potential problems are addressed quickly (Buckley, 2006).

2.4.1 i Incontinence pads

It has been reported that checking and changing of pads appears to make up a large proportion of the job description of a carer. However without frequent checking on the resident (pads and skin checking) the carer may not easily know when the resident needs changing or if the skin is in a healthy condition (Hagglund, 2010). Timely checking of pads may cause carers to work in a regimented manner, potentially causing missed detections of UI between the checks itself (Toba et al., 1996). Any delays in responding to wetness may cause residents to lie or sit in soiled pads for long periods causing discomfort, increased anxiety, distress and even skin maceration leading to pressure sore formation (Wai et al., 2008). It has been reported that nursing home residents could remain in wet pads for an hour or more on average (Toba et al., 1996). Checks carried out in the night causes restlessness in patients and it is difficult to get residents back to sleep after they have been checked or changed (Getliffe and Dolman, 2007). It has been reported that a 2 hourly prompt and checking system may be used which is consistent with nursing regulations, although this also specifies how often staff should be in contact with the residents (American Health Care Association, 1987). Holistic approaches to incontinence care might avoid this regimented scheduling so that residents are might be treated with more individual care. All the homes in the author’s study reported that the use of containment products such as pads were the main protocol for management. Much effort has been put in to improve the performance of pad design however they are still prone to frequent leaking which may lead to embarrassment and discomfort (Getliffe et al., 2007). Putting a pad on someone often has been reported to be not accepted as continence management but means of continence control (Phair and Good, 2001). The current practise involves the carer conducting periodic checks leading to unnecessary visits. Even though incontinence pads are frequently used as a management technique it has been reported that older people may prefer the use of medication over pad use (Johnson et al., 2001, Price, 2011). Although pads may allow the gaining of independence and could aid in discreet management it does not treat incontinence (Du Moilin et al., 2009). In fact it has been reported that the use of pads increases the risk of developing urinary tract infection, so regular toileting and frequent pad changes are important to reduce this risk (Omli et al., 2010). Pads are sometimes seen by some as a quick fix and so authorities may sometimes be too quick to prescribe pads when other treatments are available (Brooker and Nichol, 2003). The local council provide free pads to each home and this is allocated to the residents. However most homes in the authors study reported that pad use exceeds allocated numbers. In particular, the larger homes sometimes use up to double the number of allocated pads per resident per day. The National Health Service (NHS, UK) spends 1% of the NHS budget on incontinence products and the rise in the ageing population will indefinitely place additional stressor on the health care budgets. The National Audit of Continence care reported that the use of containment products were the preferred method for management. Supply of products are based on the residents clinical needs although supplies are usually rationed (RCP, 2006). It was reported that pads provided by the local council (provided by the NHS funding) are chosen and allocated and are not the best product, sometimes may cause skin irritation and may not be enough capacity and one home reported that they accept this although they wish that the product could be better. Forcing people to use uncomfortable incontinence pads or allowing them to sit in the soiled pads and clothes are two of the clearest examples of degrading and inhumane treatment that currently go unchecked. In addition people are made to wear incontinence pads rather than being helped to use the toilet. Clearly this is unacceptable (Alzheimer's Society 2013). In terms of toileting a resident, it may be difficult to do so because of the behavioural challenges the carer would have to face with just to get the dementia sufferer to get to the toilet and to understand the need to void (Getliffe and Dolman, 2007).

2.4.1 ii Toileting programs

It has been reported in several studies that scheduled toileting such as timed voiding, habit training and prompted voiding can significantly reduce the severity of UI among severely impaired care home residents (Schnelle, Newman and Fogarty, 1990; Schnelle et al., 1991; Burgio et al., 1994). However it has been reported that it is extremely difficult for staff in a typical care home to maintain an effective prompted voiding program over long periods of time. It should be noted that prompted voiding can reduce day time frequency by up to 40% to 50% (7 am - 7 pm) however it is more efficient if the residents responded with no limitations in cognitive awareness or behaviour (Ouslander et al., 1995). All the homes investigated in the author's study reported having a monitoring program for each resident for managing their incontinence (so that pad allocation and toileting prompts may be identified), although one home commented that 'residents are still incontinent even with this programme'.

2.4.1 iii Catheterisation

People with dementia and incontinence are more likely to receive incontinence medications and indwelling catheters than those with incontinence but without dementia (Grant et al, 2013). Nursing homes that have a high prevalence of urinary catheterization among their residents provide a less proactive approach in toileting regimes and leave catheters in situ for longer periods of time (McNulty et al., 2008; Price, 2011). Among the elderly residing in care homes, it is unfortunate that urinary catheters have been independently associated with increased mortality and morbidity (Kunin, Douthitt and Dancing, 1992; Eriksen et al., 2007). Staff in these homes suggested that staff shortages and lack of catheters care plans increased the length of time for a catheter to remain in situ as regular toileting regimes and pad changing were more difficult (McNulty, 2008; Price, 2011). Inappropriate use of catheters in care homes could lead to urinary tract infections and other health problems, which although would help limit urine leakage, would cause more harm than good (Price 2011). Care homes that focus on the individual needs of residents (more structured toileting and washing routine that are more work intensive for carer but better for residents) compared to homes that have regimented task centred care (with less proactive approach to toileting or impeded by limited staff) have been reported to have fewer catheterization residents (Davies, 2003). Staff shortages, less committed staff, and time pressure prevent carers from toileting residents and changing continence pads often enough (McNulty et al., 2008). As a result, if not catheterised, there have been frequent reports that residents will spend long sitting periods on wet continence pads (McNulty et al., 2008). The use of catheters is invasive, uncomfortable, restricts movement, reduces independence and reduces the dignity of people. In homes with higher prevalence of urinary catheter use, it was considered that the numbers of catheters used may be reduced if there were more staff to undertake toileting. However, homes with lower prevalence of catheters interestingly reported adequate staffing (McNulty et al., 2008).

2.4.1 iv Return to continence

In the author's study three quarters of the carers reported that incontinent people with dementia would never return to full or near full continence, with the reason for this being highlighted by one home as mainly due to the cognitive capacity of the individual. The remainder of the homes in this study reported that it was possible to achieve near or full continence "occasionally", although this was only possible with support or assistance. The fourth International Consultation on Incontinence (ICI) introduced a generalized paradigm for elderly for UI. In this paradigm, maintaining dryness in the incontinent individual can be achieved through ongoing assistance, behavioural treatment and, or medication (dependant continence). In this case, UI would return without the consistent assistance provided by the carers, which in most cases would be bespoke, being tailored to the individual's micturition patterns. Ongoing treatment is not required for people who have independent continence as they would be cured through anti-incontinence surgery. People who are unable to achieve independent or dependant continence would fit into the category of contained incontinence where they are managed in conjunction with incontinence products (ICI, 2009). These products include pads, catheters and other containment products (male and female urinals, commodes, clips), and this therefore would provide the accepted social incontinence. The outcome of incontinence care encompasses the avoidance of nihilism and neglect and preserving comfort and dignity (ICI, 2009). Sensor technology may be combined in relation to this paradigm as one that could assist with the management of incontinence in any stage.

2.4.2 Perceptions on using sensor technology

Technology is increasingly being used to support individuals, including the elderly, to maintain their independence and improve safety, in order to reduce the burden on the healthcare and care home sectors (Buckley, 2006; Wai et al., 2010). The responsibility of care on the carers is reportedly very high and most often this may be portrayed as a burden (Upton and Reed, 2005; Getliffe and Dolman, 2007; Rodriguez, Sackley and Badger, 2006; Jarrold and Yeandle 2009). Within the care home setting carers reported that the use of technology reduced their fears on intrusive checking, allowed more breaks from care, promoted confidence in safety of the patient and improved carer-patient relationships (Wai et al., 2008; Getliffe and Dolman, 2007). Carers also reported feeling positive about technology and the relief it gave them (Dunk and Doughty, 2008). In terms of the people with dementia, the carers reported that technology allowed for a better night's rest, reduced fears from intrusion of checking, and reduced worry (Wai et al., 2008; Dunk and Doughty, 2008; Getliffe and Dolman, 2007). The use of technology has been found to support people with dementia and was compared among a large group of people with dementia in Northampton and Essex (Woolham, 2006; Jarrold and Yeandle, 2009). One hundred and twenty three carers were surveyed and of the 70% responded they reported that the use of technology to assist with daily living reduced levels of stress and cost (Woolham, 2006). In particular technology has been used to remind a person to take their tablets at the right time, assistance to make phone calls, switching lights on or off automatically and alerting carers or monitoring the person in case of assistance needed. It has been reported that there is increasing evidence that technology can make a difference to individuals and carers in addition to the health care system (CSIP, 2006). A pilot installation of assistive technology and electronic technology to support people with dementia showed that in particular alarm events used, were detected by equipment and appropriate responses were made which avoided the risk to hospital treatment (Dunk and Doughty, 2008; Van Den Heuvel, Jowitt and McIntyre, 2012). Interestingly technology could help reduce the admission to institutional care or in some cases to delay the need for this type of care (Bayer, 2007). It is apparent that technology can make important contributions to care such as safety, security, independence and quality of life of elderly people in care home. Although many carers might welcome the use of technology, there may be a few who might view it as an invasion of privacy (Miskelly, 2001). In terms of using technology for incontinence detection, carers have expressed that false alarms in detection might disturb the traditional care-giving process by creating unnecessary frequent visits (Wai et al., 2008). False alarm rates is reported to reduce the practically of the system and carers may lose trust in using such technology (Wai et al., 2008). Carers also expressed the potential of wrong usage or misuse of the technology. This was described as carers not knowing how to replace or clean UI sensors which could affect the detection criteria (Wai et al., 2008). Carers seemed to be more willing and open to UI detection technology when training and education was provided on how to use such a detection system (Wai et al., 2008). Based on this, technology could be important if used in parallel to a sustainable health and social care system with the ever increasing number of people with dementia. However it is important to point out that technology should be carefully designed around the carers who work directly with the people with dementia. This could avoid compromising care quality as the demand grows. Technology has the potential to support more effective delivery of better care home services for both carer and people with dementia and most importantly it makes economic sense (Jarrold and Yeandle, 2009).

2.4.3 Desired design of sensor technology: solution to detecting UI

There are many incontinence detection devices on the market mainly aimed at children for the purpose of toilet training (Wai et al., 2008). These products are also aimed for home use which involves localised monitoring and not for simultaneous management of a large number of users receiving continence care such as in care homes (Wai et al., 2008). The limitations surrounding the use of incontinence detection technology by carers include: lack of competency of carers using sensor technology, short wireless range, only one user per sensor unit, invasive placement and the need for additional cleaning by carers (Wai et al, 2008). When a micturition monitoring detection device using a thin layer membrane embedded in a diaper was tested in elderly patients, it was found that shorter time was found spent being in wet pads than with the traditional approach to scheduled checking although the increased frequency of changing pads doubled the carers work load (Toba et al., 1996). In the case of sensors in pads, it may appear to be highly sensitivity in detection UI requiring carers to devote their time to changing pads (Toba et al., 1996) with the added possibility of cleaning and replacing sensors. Many UI detection devices are currently on the market, however clinical proof of their effectiveness for incontinence management of people with dementia is lacking. This could be due to lack of understanding of management of incontinence works in dementia homes and the aspects of product design to closely match the needs of a carer (Biswas et al., 2008). For carers to have confidence in using sensor technology for UI detection it is important that the sensors are reliable, non-intrusive and provide continuous monitoring with a minimum false alarm rate. It should also be easy to use and simple in order to reduce the burden on carers (such as no cleaning or handling of sensors required) as well as notification on battery and connectivity problems. Using a sensor detection system it is important to scrutinise the effectiveness of a system from a practical perspective, in case carers get easily distracted from responding to prompt reminder events (Wai et al., 2010). A system that could address the need for pad changing following UI may allow fewer demands made on the care givers. A system that is easy to use with minimal extra work loads coupled with training on how the system works may encourage carers to be interested in such a system (Wai et al., 2008). The use of technology in the healthcare environment (for monitoring long term conditions: diabetes, heart failure and COPD) has been studied in one of the largest randomised controlled trial of telehealth and telecare in the world (Department of Health, 2011). This study involved 6000 patients and 200 GP practises across three sites in the UK: Newham, Kent and Cornwall. The aim of the study was to find out if the uses of technology such as remote interventions make a difference. Adequate delivery of technology may substantially reduce mortality rates (by 45 %), reduce the need for hospital admissions (14 %), lower the number of bed days spent in hospitals (14 %) or reduce the time spent in the Accident and Emergency department of hospitals (15 %) (Department of Health, 2011). This highlights the positive aspect of technology, where lives have been improved. It may be possible that sensor detection technology described specifically in this study could help with improving management of urinary in continence in people with dementia in care homes if it was given the opportunity for a trial. In the authors study, some carers were found to be reluctant towards the idea of using sensor technology although they would be willing to consider the idea if they were provided with training and support. It is important to note that even with the carers who agreed on its benefits, sensor technology should not be used independently to avoid creating dependence (from the carers) or the possibility of neglect and misuse, due to the high staff turnover rate that exists in care homes. Carers may be concerned about information overload with irrelevant information and technology detracting from the traditional methods of care (Kang et al., 2010). Other prohibitive factors included lack of funding for instrumentation, data collection and the skill of interpretation of data. The reported risks associated with using technology for patients are privacy, unfamiliarity with technology and potential decreases in social contact of sufferer. However better understanding and application of technology may improve lifestyle to prevent the over use of pads (save money) and encourage the promotion of continence (Price, 2011). Clinical research has highlighted the benefits of telecare in supporting people with dementia, delivering care within the familiarity of the home environment (Buckley, 2006). The benefits of using telecare include reduced the entry rates to institutional care homes (where they remain for several years) or even postponed admission (Bayer et al., 2007). Carers may benefit from the use of technology that could record incontinence incidences as an effective way to permanently record and address individuals at risk (Upton et al., 2005). The quality of care could be greatly improved using the statistical analysis of a behavioural history of incontinent residents to anticipate voiding times for these dementia residents, so that they may be brought to the toilet before passing urine (Wai et al 2008). It is important to recognise that the carers experience in caring for incontinence sufferers may help designers to value interventions by care givers through their recommendations from the direct relationship with long term care provision (Upton and Reed, 2005). Existing UI detection sensors that are on the market are invasive and may only detect moisture when in contact with urine. These sensors may be attached to the skin or embedded in an incontinence pad which could be uncomfortable for residents, or difficult for carers to clean, replace and generally manage it. An ideal system sensor detection system for an incontinent dementia resident would be one that is embedded in the bed or a seat rather than on the person clothes (58 % of the 12 carers who answered felt this way). There is strong objection to the use of wired connections attached to patient because it may affect their safety, comfort and possibly mobility. A wireless system is slightly more desirable probably due to the portability nature (56 % of the 16 carers answered this). Small sensors (life RFID tags) would be ideal as larger sensing components might not be desirable (Biswas et al., 2008). It is envisaged that the humidity sensors would be able to detect increases in sweat which can permeate through clothes. This has been detected using humidity sensors in the sitting experiments in laboratory environments (chapter 4) by the author. The humidity surrounding the expel of urine into a incontinence pad will eventually permeate through the pad material and clothes of the individual and the idea of using humidity could reduce the chance of the person sitting or lying in an area that has too much humidity surrounding the skin. Embedding the sensors in the seats mean that levels of humidity may be detected external to the human body. Carers seem to not like the idea of alerting incontinence to a central computer system (82% 0f the 11 carers who answered) although there was only a 50 % (of 16 carers that answered) acceptance in having alerts through to a mobile phone device. When it came to bedside alarms, 67 % of the carers did not want this and alerting discretely is reported to be preferred (64 % of 17 carers who answered). A battery powered system is also a favoured option. Carers may not hear an alarm if they are far, the loud alarm may affect the resident (Ang et al., 2008). Carers in this study have indicated that technology should be implemented in the care home setting in order to know that it works (Department of Health , 2011). Trialling of sensor detection technology in the care home setting needs to be increased for longer periods in order to prove the efficacy of such a system (DoH, 2011).

2.5 Conclusion

Evidence from the study suggests that carers who agree to using sensor detection technology to detect UI in dementia reported that it may benefit a busy caring environment provided they are used in line with the traditional care approaches. Carers would like to use sensor detection technology provided they were given training and support and that they were less involved in the cleaning and maintenance of the product. Carers spend the most amount of time accommodating residents that their design requirements could be most valuable to creating a product suitable to work in their environment. The discovery of technological needs for assisting with management may be more successfully utilised if it were custom designed by carers themselves to support the carer appropriately. There was a small group of carers who did not wholeheartedly embrace the use of sensor detection technology due to the possibility that dependency on technology may slow down management, it may not be suitable for residents with higher functioning cognition, breach of patient confidentiality and the preferred traditional approach to care. Part of the concerns included the loss of the traditional carer – resident relationship. The reduction of carer-resident relationship could potentially slow down management by the reduction of regular visits to the resident due to only attending to them when the sensors react to the presence of urine. In these cases the heavy reliance on the traditional methods of checking and toileting seemed a preferred method by carers as it is personal and information about the status of the person being checked at that moment in time is private. It is also feared that a sensor detection system where alerts of a UI episode may cause breach of patient confidentiality. Behaviour was the key factor associated with the challenges in managing incontinence even when carers reported that they were happy with their current approach to management without the use of technology. The manifestations of carers who did not perceive the usefulness of sensor technology was important to consider however this study revealed a higher percentage (70%) of carers who agreed to the benefits of using sensor detection technology. These carers reported that traditional approaches to management are time consuming and demanding for an environment of high staff turnover and or shortages. It has been mentioned earlier that checking, changing and toileting dementia residents take up the majority of the job role. The main reason for the high staff turn-over rate and shortages is the difficulty in staff recruitment, and new carers often lack the appropriate skill and subsequently would have to learn on the job. Some of these people have not experience working within a care home environment and unfortunately care home do not cater for ongoing training in the basic elements of care such as manual handling, dementia awareness, infection control. This means that residents are not cared by the same staff all the time and less than adequate care may potentially be given due to staff not being aware of recent issues and concerns. Morale is also linked to the quality of care delivered by the carers however with the amount of burden highlighted it is likely that morale may deteriorate. Sensor detection technology could benefit a busy caring environment provided they are used in line with the traditional approaches. Carers should be encouraged to maintain their existing protocols, although the levels of humidity detection that the sensors pick up could be read externally by the carer in order to know how 'wet' the individual is without invasive checking. It may not however support a direct route back to continence although the simple assistant of sensor detection would ensure that any incidences between checks or even accidental fluid spillage from fluids and drinks may be detected immediately through humidity detection. Using humidity to detect increases in moisture means that the sensors do not need to be invasively placed on the person. This detection approach is useful because people with dementia may have difficulties in asking for help communicatively. The decline in cognition and physical mobility in dementia residents in care homes (Wai et al., 2010) causes them to be mostly seated in the day time and then usually lying during the night time. People with dementia do not have quick mobility so if there are increases in humidity detected due to incontinence, carers may be alerted to the chair or bed they are lying on. Residents will most probably stay in the soiled seat or mattress or any attempt to leave that area would be a very slow process anyway. This means that carers will always know who has been incontinent. This takes away the tagging of residents which may breach the confidentiality of residents. Carers would like to use sensor detection technology provided they were given training and support. Carers spend the most amount of time accommodating residents that their design requirements could be most valuable to creating a product suitable to work in their environment.

2.5.1 Closing statement

Investigating the feedback from carers formed the requisite to verify a suitable sensor detection system that is a more quantifying and non-invasive system. Building on this, Chapter 3 will utilise rigorous testing and calibration methodologies to investigate the validity, reliability and ultimate suitability of a device for use in the detection of humidity (incontinence detection) at the seat surface of a person in a care home environment. The qualitative comments and quantitative information from the survey will form the criteria for the laboratory testing. Once the capacity of a detection system is understood within a laboratory conditions, it will then (Chapter 4) be tested on human subjects (care home sitting simulation) to confirm its suitability within the real life setting.

Chapter 3

Performance verification of humidity sensors traceable to national standards

"Anything that is theoretically possible will be achieved in practice, no matter what the technical difficulties are, if it is desired greatly enough" - *Sri Lankabhimanya Arthur C. Clarke.*

A non-invasive and quantifying system was found to be desirable, based on the perspectives of carers on an ideal sensor detection system (*vide supra*). After researching current incontinence detection products on the market at that time, there was no indication that any humidity based sensor detection system was able to detect the presence of the effects of incontinence external to the site it originated from on the human body. Humidity sensors are able to quantify the proportion of water vapour. The system described in this thesis encases the sensor in a material capable of allowing water vapour to permeate and it may be possible to detect changes in humidity at the seat and person interface. Hence this system would allow for a non-intrusive approach to measuring incontinence. This research aim of objectively identifying the outcome of incontinence was underpinned by the aim of maintaining the dignity of people with dementia. However, the challenge in using humidity sensors is maintaining accuracy through calibration. This chapter investigates the interaction between humidity sensors and the environment under laboratory conditions by regularly calibrating the sensors (traceable to National standards) to determine variance of the output, variance over time and the potential for the environment to affect the variance, in order to better understand the characteristics of the technology.

3.1 Introduction to the study

Continence pads are often used to manage incontinent dementia patients and regardless of the design, leaks still do happen. When a pad leaks, urine may spread through underwear, clothing and eventually to a seating surface causing added pressure of laundry, cleaning furniture and additional checks (Van Den Heuval et al., 2011). Dementia sufferers spend long periods of time sitting during the day therefore it is more than likely that there could be an interaction between the environment, human body and the properties of the materials comprising the seat such as the seat covers, cushion material and mattress material (Stewart and Cochran, 1980; Ferguson-

Pell et al., 2009; Alzheimer's Society, 2013). A variety of incontinence detection devices have been developed and used however many involve skin contact, on clothes attachment or a wired application (Yamada et al., 2010; Wai et al., 2008; Van Den Heuval et al., 2011; Lewis et al., 2012; Ang et al., 2008; Nilsson et al., 2005). Even with the use of these devices, carers still have to manually and repeatedly check patients for wetness (Lewis et al., 2012). Chapter 2 reported that an ideal incontinence detection system for dementia residents would be one that is non-invasive, (wireless) and embedded in a seat so that the product appears to be invisible to the user and reports discretely to the carer thus maintaining dignity of, and preventing undue alarm to the user. Since humidity is a property that is able to penetrate through materials it may be possible to achieve 'non-invasive' and 'non-person contact' measurements provided that the trigger levels of body exudates (urine excretion and perspiration) are fully understood (NPL, 2012). Sensors technologies used for incontinence devices may include infrared (Ding, 2013), accelerometers (Carney, Elfström and Bosaeus, 2013), conductive wires (Ortega and Sciarra, 2012), peizoelectric technology (Yonezawa, Ogawa and Mukai, 2009) however humidity sensors are rarely used (Ales et al., 2010). When person with dementia sits for prolonged periods of time, the temperature will increase at the interface between the seat and the skin, which would be expected to trigger a sweating response locally (Cascioli et al., 2011). Prolonged exposure to increased humidity and liquid (from UI and sweating) is known to damage skin viability (Bader et al., 2005) and may cause an additional rise in humidity of the microclimate between the person and seat surface. This raises an interesting possibility that there may be humidity variations in the microclimate (from sweating and urinary incontinence) which could be detected. To the author's knowledge not many studies have utilised humidity sensors that could be used external to the human body to specifically detect incontinence (McCarthy et al., 2009). Some studies have indicated that body humidity could be an important property to investigate in order to understand the microclimate of the sitting interface between a person and seat surface (Freeman, *et al.,*1938; Brattgard, *et al.,* 1978; Stewart and Cochran, 1980; Cengiz and Babalik, 2007, Stockton and Rithalia, 2007; McCarthy et al., 2009; Nicholson et al., 1999; Ferguson-Pell, 2009) . Substantiating the feasibility of using humidity sensor technology for incontinence detection can only occur through understanding the basic science of humidity measurement.

3.1.1 The science of humidity and measurement

Humidity is essentially water in its gaseous form, similar to how moisture relates to water in its liquid form which is present in solid or liquid materials (Lu and Chen, 2005; Solomon, 2009; NPL

2012). Humidity is present when hot water gives off steam and also water at lower temperatures, including ice, which gives off water vapour (NPL, 2012; WMO, 2008). Water vapour is invisible and behaves like a gas, as a result it is able to react with surfaces and penetrate through materials (NPL, 2012). The NPL (2012) defines humidity as, 'The presence of water vapour in air or other gases" and is said to comprise approximately 1% of air (at sea level)'. The exact amount of humidity (absolute humidity) is challenging to measure on account of its changes in state of water in the atmosphere which can be either: ice, liquid or gas (Solomon, 2009; WMO, 2008).

3.1.1 i Problems with high and low humidity

When the temperature of air is increased, it becomes warm air and it has the capacity to hold more moisture leading to higher humidity. High humidity can cause mould and fungus to form on surfaces because the increase in moisture helps it to thrive (Kamrass and Mann, 2000). Similarly high humidity surrounding skin (especially in the elderly) may affect weaker skin or exacerbate wound healing. Exposing the skin to moisture from urine or perspiration will cause skin dampness predisposing it to incontinence associated dermatitis (Ferguson et al., 2009; Getliffe and Dolman, 2007). Incontinence associated dermatitis is an inflammatory skin condition that occurs when the skin is exposed to urine or faecal matter (Lambert, 2012). This moisture maceration injury may also occur due to perspiration, wound exudates and other body fluids and is prevalent in incontinent dementia sufferers (Gray, Black and Baharestani, 2011; Lambert, 2012). Since the dementia sufferers spend large amounts of time sitting (Alzheimer's Society, 2013) it is therefore important that moisture and humidity surrounding the area especially during prolonged sitting should be controlled by wicking moisture away from the skin (Bader et al., 2005). The increased temperatures in the home environment between 20 ^{o}C to 65 ^{o}C may cause the removal of moisture from the air (Kamrass and Mann, 2000). This may cause dryness and irritation to the lining membrane of the nose, throat and trachea and lungs. As a result of this the person may experience a sore throat, dry nose and cough. Breathing in heated air (or air that has low humidity) may cause nasal secretion to thicken and not flow (Samson, 2004). If however the temperature of that same air is reduced, then the air becomes cooler and it now is not able to hold as much moisture and so the air also becomes lower in humidity (Cassar and Hutchings, 2000). Low humidity (less than 40 %) and exposure to cold decreases skin hydration resulting in decreased pliability causing damage to the stratum corneum. Temperature changes affect the level of dyspnoea (shortness of breath). When the body is in extreme hot or cold conditions it is stressed in an effort to maintain constant body temperature of 37 °C. This happens because the body has to expend additional energy in order to warm or cool the body thus increasing the amount of oxygen needed. Bronchospasm (contraction of the smooth muscle surrounding the airways), may decrease the size of the airway when breathing hot or cold air causing a drying effect. This may cause shortness of breath. The air density increases with rising humidity thus resisting air flow in the airways causing an increase in work done for breathing. Also as the humidity rises the prevalence of airborne allergens may increase, as well as dust mites and mould (Rotech, 2005).

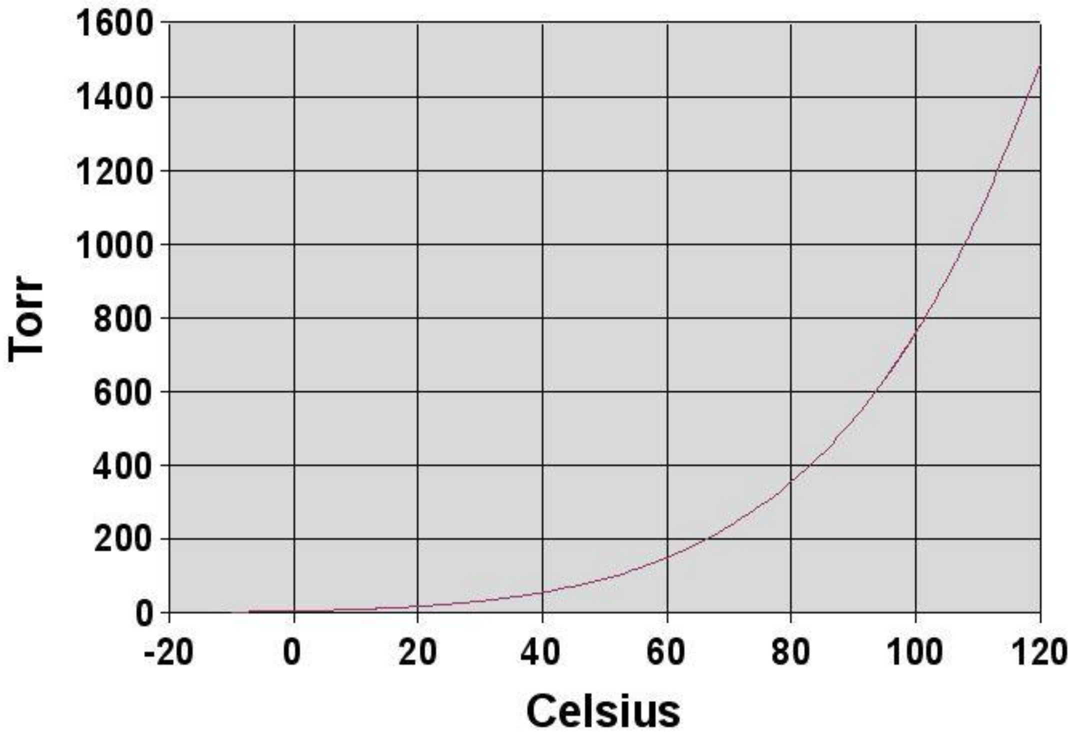
3.1.1 ii The relationship between humidity, pressure and temperature.

Humidity describes the amount of water vapour present in a volume of gas such as air which has a relationship with pressure and temperature (NPL, 2012, Solomon 2009). The average kinetic energy of water molecules from heated liquid water placed in a closed chamber is dependent on temperature. Water molecules in the surface layer will escape due to evaporation. However because the chamber is closed the escaped water molecules will bounce about on the chamber walls and if it hits the water surface it will get trapped in the water again until it regains sufficient kinetic energy and is at the surface to escape once more (Muncaster, 1993). After some time an equilibrium state will be achieved where the number of water molecules leaving will equal the number of water molecules joining the liquid. In this equilibrium state the number of gaseous water molecules will remain statistically constant and the vapour above the liquid is said to be saturated. In this situation the pressure of the gaseous state is called the ‘saturated vapour pressure’ and it is measured in millimetres of mercury (mmHg). In this closed chamber setting, the higher the temperature the higher the kinetic energy of the water molecules resulting in a high saturated vapour pressure due to more particles escaping (Horstmeyer, 2008). The gas that is in a container has a pressure directly proportional to the average force per unit area that the molecules of gas will exert on the wall of the container. It is these molecular collisions that generate pressure. This means that pressure is proportional to the kinetic energy of the molecule and therefore pressure is also proportional to temperature (Muncaster, 1993). Water that is placed in an open chamber will go through the process of evaporation at the surface. This is because the water at the surface has more kinetic energy and eventually leaves the liquid state to become a partial pressure with the surrounding gas (Institute of Physics, 2010; Sensirion, 2009). Dry air contains 79.02% of nitrogen (N_2), 20.94% of oxygen (O_2) and 0.0004% of carbon dioxide (CO_2). When water is exposed to air, molecules of water leave the liquid and enter the air, producing water vapour. The vapour pressure of water is equivalent to the partial pressure of water (PH_2O) when there is no net movement of water between the gas and liquid phases. In this case the water vapour depends on temperature only, and is independent of barometric pressure (760 mmHg) (Sensirion, 2009) on figure 3.1.

3.1.1 iii Description of humidity expressions

The physical presence of water vapour in the air can be represented in a variety of ways. The most commonly used humidity measurements are the 'absolute humidity', 'relative humidity' and 'dew point temperature' or frost point (Cavlier, 2012). Two other ways to express humidity are the 'saturated mixing ratio' and the 'mixing ratio'. The absolute humidity is the mass of water vapour (grams) in a volume of air, compared to the mass of dry air in that same volume of air and it is independent of temperature. Essentially the absolute humidity describes the maximum weight of a completely saturated (with water vapour) volume of air (may be measured in parts per million (ppm). The relative humidity (RH) is the amount of water vapour actually present within a specific volume (or parcel) of air (Cavlier, 2012). Relative humidity is a function of temperature and is measured as a ratio to the maximum capacity of humidity thus it is a relative measurement**.** Dew point is the temperature (above 0^{o}C) at which the water vapour in a gas condenses to a liquid form. Frost point is the temperature (below 0^{o}C) at which the vapour condenses to ice. Dew or frost point is a function of the pressure of gas but it is independent of the temperature and this makes it an absolute humidity measurement (Cavlier, 2012)**.** The saturated mixing ratio is the maximum capacity for water vapour that could be present in air. The unit of measure for saturation mixing ratio is grams of water vapour per kilogram of dry air. This measurement depends on temperature (warm air holding more water vapour than cold air, due to higher kinetic energy of particles). It is not affected by changes in pressure. The water vapour is not affected by heating the air or cooling the air, unless the air is cooled below its dew point and the water vapour condenses (Cavlier, 2012; Muncaster, 1993). The value of the water vapour changes only by adding or removing water vapour. Mixing ratio is measured by the amount of water vapour in grams mixed in with 1 kg of dry air. To measure traces of moisture mass it may be better to use absolute (ppm) and dew or frost point because it reveals the amount of water vapour in a gas or air. However RH is normally used because as a ratio it is easier to understand if incorporated into daily use (Chen and Lu 2005; Solomon 2005) specifically because of its relationship to temperature.

Figure 3.1. Vapour pressure of water



Key: The vapour pressure of water is equivalent to the partial pressure of water (PH_2O) when there is no net movement of water between the gas and liquid phases. In this case, the water vapour pressure depends on temperature only and is independent of barometric pressure (760 mmHg). Torr is a unit of pressure, with 1 Torr being equivalent to 1 mm of mercury in a barometer and is equal to 133.32 Pascals **(adapted from Yannick Trottier, 2006) http://commons.wikimedia.org/wiki/File:Water_vapor_pressure_graph.jpg**

3.1.1 iv Relationship of the humidity expressions

Relative humidity is related to both temperature and pressure and is defined as the ratio of partial pressure of water P_i to the saturation pressure of water, $P_{sat\,(T)}$ (over water) at a specific temperature of gas. This equation may be expressed as follows: RH% = $P_i/P_{sat\,(T)}$ x 100%

In relative humidity measurements, the total pressure is not included in the equation because saturation pressure of water is needed which happens at a specific temperature. Interestingly if temperature is above 100 ^oC the saturation pressure of water vapour will be greater than 760 mmHg making it impossible for the RH% to reach 100 % in an unpressurised system. Below 0 ^oC a 100 %RH is also impossible to achieve due to condensation occurring at lower humidity than 100 %RH (when water vapour is saturated against ice). Absolute humidity is a measure of the actual amount of water vapour in a parcel of air. This may be measured as the partial pressure (mmHg), a mixing ratio (gm water vapour/kg dry air) or the dew point. The following example shows how absolute humidity may be derived from relative humidity. If at a particular environment of 32.2 ºC the air is 80 %RH then the following relationship for relative humidity may be made for absolute humidity (Pi is the partial pressure of water and $\mathrm{Psat}\,(T)$ is the saturation pressure of water at a specific temperature):

Relative humidity = $\frac{\mathrm{Pi}}{\mathrm{Psat}\,(T)} x\ 100$

Now using the temperature 32.2^{o}C, the saturation pressure of water may be located from a saturation pressure table as 36.09 mmHg (appendix 2a). Therefore the partial pressure of water vapour (P_i) may be computed as follows:

80%RH = $\frac{\mathrm{Pi}}{36.068} x\ 100$;

P_i = 0.80 x 36.068 = 28.854 mmHg *(this is the partial pressure of water at* 32.2^{o}C***)***

The P_i may then be used to calculate the absolute humidity (Pi is the partial pressure of water; MWi is the molecular weight of water; P-Pi is the total pressure of water minus the partial pressure of water; MWdry is the average molecular weight of dry air):

Absolute humidity (AH) = $\frac{Mass\ of\ water\ vapour}{Mass\ of\ dry\ gas} = \frac{\mathrm{Pi\ x\ MWi}}{(\mathrm{P-Pi})\mathrm{MWdry}}$

AH = $\frac{(28.854mmHg)x\ (18gH2o/mol)}{(760mmHg-28.854mmHg)x\ (29gail/mol)}$ = 0.024 *g/m*^{3}

Absolute humidity is the amount of water in unit amount of air weight whereas relative humidity is the amount of water in unit amount of air by partial pressure and temperature. In absolute humidity the saturated pressure of water is not used because of its relationship to temperature. Instead the total pressure of water is used. Although absolute humidity is the concentration of actual water vapour present in air, how much the air can carry is determined by pressure and temperature and this is why relative humidity is often the preferred method for expressing the presence of humidity (Cavlier, 2012; Muncaster, 1993).

3.1.2 A chronological introduction to humidity measurement devices

Measuring humidity is an important requirement in many areas of human life today, and it often involves continuous recording using a wide range of techniques and devices (NPL, 2012; WMO, 2008; Chen and Lu, 2005). Early methods of measuring humidity included the use of human hair or a nylon film, and the wet and dry bulb methods. These instruments are known as hygrometers (WMO, 2008). Hygrometers depend on measuring quantities such as temperature, pressure, mass or a change in mechanical or electrical property of a material or substance as moisture is absorbed. Displacement sensors are the oldest type of mechanical sensors which uses a strain gauge or other mechanisms to measure expansion and contraction of material (hair, nylon and cellulose) in proportion to changes in RH%. A major concern in this area is the relative difficulty to find highly accurate calibration devices for humidity generation and measurement, thus making it difficult to confirm the accuracy of any humidity measurement (Sensirion, 2009; Vaisala, 2010). Table 3.1 contains a chronological list of devices developed through time.

3.1.2i Problems with accurate humidity measurement

Measurement of humidity is more difficult than measuring temperature or pressure and this is because humidity is found in a broad range of atmospheres (Solomon, 1998; Cavlier, 2012). Humidity has a broad dynamic range beginning from 10 parts per billion (ppm, representing a partial vapour pressure of 10^{-9} in Hg) to steam at 100^{o}C (representing a dynamic range of more than 10^{9} Hg (Solomon, 1998). The WMO (2008) stated that "the achievable accuracies [for humidity determination refer to good quality instruments that are well operated and maintained although in practice, are not easy to achieve." When humidity measurement is compared to temperature measurement, it can be seen why there are challenges with the humidity aspect. The method for calibrating thermometers involves immersing a pair of

Table 3.1. Chronological list of humidity measurement devices.

Leonardo da Vinci (1400s): A scale containing a hygroscopic substance (sponge, cotton or wool) in one tray and a hydrophobic substance in the other (wax). When the air moisture increases, the hygroscopic substance absorbs the water thus increasing its weight, tipping the tray which is indicated on the scale (Kifissia Meteo, 2013)
Francesco Folli (1664) This hygrometer consisted of a brass frame in the shape of a balustrade which carried a small roll on the top and bottom of each structure. Each small roll is wrapped with the end of a paper ribbon serving as a hygroscopic substance. At the centre of this brass frame, there is a brass dial mechanical system, with an integrated pointer, which moves as the length of ribbon changes due to variation in atmospheric humidity (Kifissia Meteo, 2013).
Horace-Bénédict de Saussure 1783: The hygrometer is placed in a wooden case with a glass door. Within the wooden box there is a mercury thermometer with a scale from -20°C to +35°C and a strand of hair. When the air humidity increases, the strand of hair dilates. Two cylindrical shafts are in the front part of the apparatus which support an 8 cm in diameter circular ring, on which there is an engraved scale. This scale is marked in increments of 10 from 0° to 360°. A horizontal axle installed between the scale ring and an additional rear shaft moves, with a pointer. The strand of hair is wound to a screw on the axle, next to the face of the dial. The action of a 'cord winding' on the screw will adjust the tension of the hair shaft. Some instruments used whale bones, ivory strips, swim-bladders in the place of hair. The instrument can be made more sensitive by removing oils from the hair, such as by first soaking the hair in a solution of diethyl ether (Innovateus Inc., 2013). It is low in cost and low contamination. However the limitations include drifts over time and loss of sensitivity.
Duke Ferdinand II de' Medici 1667, developed by John Frederic Daniell in 1820, and perfected by Henri-Victor Régnault in 1845: This device used the relationship between the temperature of the 'dew point' temperature and the atmospheric humidity. This device consisted of an impermeable truncated cone lined with glass, positioned at the bottom of the device. This cone is filled with finely ground ice. When the humid air contacts the iced glass, condensation occurs and water droplets form which descend to the apex of the cone to gather in a glass. Higher atmospheric humidity results in higher condensation. The amount of water gathered in the glass over a period, represents the relative measure of the humidity (Innovateus, 2013).
Adolph Richard Abmann (1845-1918): The psychrometer consists of two thermometers referred to as the dry-bulb (always dry) and the wet-bulb (maintained damp with distilled water on a sock or wick). If the area being measured has a temperature that is higher than the freezing point of water, then evaporation from the wick causes a decrease in the temperature of the thermometer showing a lesser temperature than the dry thermometer. However if the air temperature is lesser than the freezing point, wick of the wet bulb may be enclosed in a coating of ice which possibly insulates it and appear warmer than the dry bulb. The dissimilarity of temperatures between the wet and dry bulb thermometers would indicate the relative humidity (calculator using the atmospheric temperatures) from a psychometric chart in appendix 2b (Innovateus, 2013).

Key: This shows a chronological list of hygrometers created through time. Hygrometers depend on measuring quantities such as temperature, pressure, mass or a change in mechanical or electrical property of a material or substance as moisture is absorbed. Displacement sensors are the oldest type of mechanical sensors that uses a strain gauge or other mechanisms to measure expansion and contraction of material (hair, nylon and cellulose) in proportion to changes in RH%.

thermometers in a vessel insulated with water (or alcohol, for temperatures below the freezing point of water) and stirring them vigorously to reduce variations of temperature (NPL, 2012). If this is carried out in a stringent manner, a high quality thermometer can remain stable for some years (NPL, 2012). Humidity measuring devices such as hygrometers must be calibrated in air and as air is a less effective heat transfer medium than water, it can be subject to drift therefore requiring calibration (WMO, 2008). Another reason why it is difficult to measure is because humidity is always interfered by contamination in the form of particles or chemical as well as varying temperatures (Solomon, 1998). More recently technologically advanced semiconductor methods have been developed (Table 3.2). However, all of these have mixed advantages and limitations to their use (Silicon Laboratories Inc., 2012; Cavlier, 2012). Electronic devices that utilise sensor technology use the temperature at the condensation level (dew point), or changes in electrical capacitance or resistance to measure humidity differences. Again accurate humidity measurement may be achieved through calibration and appropriate calculation. However it has been reported that calibration of humidity sensor based measurement devices may also be technically challenging (Silicon Laboratories Inc., 2012).

3.1.2 ii Background on Humidity sensors

There has been an increasing demand for highly accurate humidity sensors in healthcare applications for environmental (pressure sensor mats) and personal monitoring (enuresis sensors) particularly in smart homes (Chen and Lu, 2005). Research and development aim to improve the performance of humidity sensors, especially in terms of: accuracy, reliability and speed of measurement (Solomon, 2009; WMO, 2008). Humidity sensors created from a variety of technological designs are unable to measure the full range of vapour levels, therefore different methods and sensors have been developed through the years (Chen and Lu, 2005). Each of these have advantages and disadvantages regarding the type of humidity (absolute or relative) that is to be measured (Solomon, 2009; Roveti, 2001) (Figure 3.2).

3.1.2 iii Relative humidity sensor technology

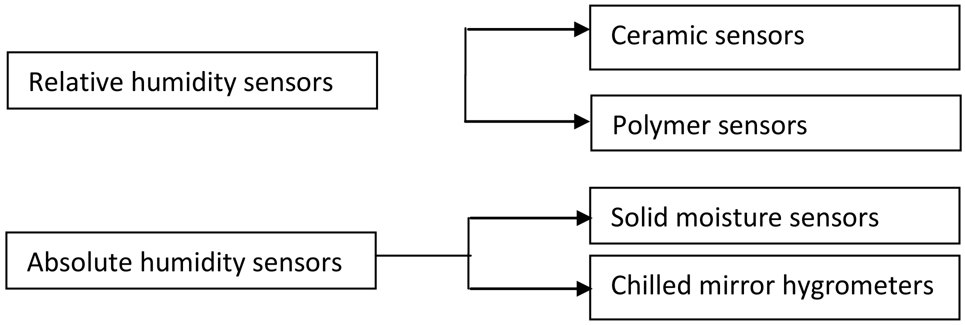
Ceramic sensors work on the basis of water being adsorbed on the surface of a ceramic material, and protons conducted on this surface (Chen and Lu, 2005). Polymer based humidity sensors are made up from long chains of carbon linked atoms that form polymers. Polymer based humidity sensors have been researched and used for more than 30 years (Soloman, 2009). The polymer sensors exhibit less temperature dependency (temperature coefficient)

Table 3.2: Description of commonly used humidity measurement devices.

Device	Description
Chilled mirror hygrometer	The quantity of reflected light is detected by an optical detector. High reflection means mirror surface is above dew point and maximum light received is detected. Accurate (±0.1ºC), reliable and used as a calibration standard where traceability is required. In contrast they require skill of an operator as these devices are prone to contamination on the mirror surface.
Gravimetric hygrometer	Measures the mass of an air sample and compares to the same amount of dry air. Considered accurate in determining the moisture content in air. Commonly used to calibrate less accurate instruments
Multimeter	Portable battery operated devices and microprocessor based systems which are able to display measures in terms of dew point, ppm or RH%. Water vapour penetrates the capacitor (aluminium oxide sensor which is basically a capacitor) and is absorbed by a porous layer. The number of water vapour molecules absorbed determines the impedance of the capacitor and in turn is proportional to the water vapour pressure. It can operate over a wide span of humidity values, however it must be periodically calibrated to accommodate ageing effects, hysteresis and contamination.
Electronic hygrometer	A dry gas measurement device consisting of a bifilar winding of inert electrodes on a fluorinated hydrocarbon capillary. DC applied to the electrodes disassociates the water absorbed by sensor into hydrogen and oxygen. The current represents the number of molecules disassociated. May not be recalibrated but only replaced. The device covers a range of 0 to 1000ppmv with accuracy of ±5%RH. Suitable for low contamination industrial use such as semiconductor manufacturing. However it cannot be used in corrosive environments containing acids, ammonia, chlorine and alcohol so would not be appropriate for detection of incontinence.
Dew cup devices	Condensation occurs on a chromium copper plated surface when cooled using dry ice. Dew is observed by the operator. Accurate above freezing point of water however prone to incorrect reading due to operator perspective, high air velocity, contaminated air and poor lighting conditions.
Fog Chamber	Small air pump holding a sample of air under pressure in a chamber. The gas is measured by a thermometer and a pressure ratio gauge. Once the temperature is stabilised a valve is depressed releasing the pressure which causes adiabatic cooling and visible condensation or fog to form, and is observed under a beam of light. Measurement errors are at 5ºC.
Piezoelectric hygrometer	A hygroscopically sensitive crystal is exposed alternatively to wet and dry gas. Dry stream passes through a molecular sieve dryer to remove moisture. A wet stream is passed over measuring crystal and moisture is absorbed by the crystal, causing a vibrational change in frequency. Vibrations are measured using a piezoelectric sensor in a microprocessor. Good repeatability and accuracy but expensive.
Peltier device	Thermoelectric cooler for fast humidity sensing. An optical signal of a photo detector was studied when water condensation appears on the cold side of the device. When cooling, water drops form and the applied current is stopped. A reverse pulse of current is quickly applied to return back to ambient temperature. High cost, frequent mirror contamination and instability occurs with continuous use.
Saturated salts (lithium chloride)	A bobbin covered in an inert electrode and dipped in a salt solution of lithium chloride is heated (resistive heating from AC current induced) causing the surrounding water vapour to evaporate. When bobbin dies out, salt solution increases in resistance, causing less current to flow and bobbin cools down. This happens alternatively until the temperature stabilises with surrounding air. Accuracy is ±1ºC although errors may occur from contaminated sensors. It has slow response and electricity must be continuously supplied as well as it has to be kept in environments of less than 11%RH.
Thermal conductivity sensors	Polymer resistive and capacitive sensors are popular sensors because it has a high degree of performance and accuracy. They are secondary measuring devices requiring periodic calibration against a certified calibration standard that is time consuming and costly.
Psychrometric	Two thermometers: dry-bulb and the wet-bulb (damp wick). The difference in temperatures between the thermometers intersect on a chart to give the RH. Simple, low cost with high accuracy near **100%RH** (min. error). Contamination of the wick can cause interference and higher RH values, although wicks can be repaired or replaced.

than other older RH sensors such as the Pope or Dunmore cells. They usually operate at room temperature due to its high sensitivity to heat. The polymer film contains micro pores for water vapour to condense on which changes the physical properties of the film which is measureable. Polymer sensors are usually within the accuracies of 1 %RH in narrow ranges and ± 3 %RH when newly calibrated over a broad temperature and humidity range. Polymeric humidity sensors are traditionally divided into resistive type and capacitive type sensors. Resistive type sensors respond to moisture by changing its conductivity. The capacitive sensors respond to water vapour by varying its dielectric constant. The choice of sensors depends on the application and table 3.3 displays the differences between the two technologies. In capacitive sensing technology, conductivity depends on ambient humidity and ensures a full measurement range from 0 to 100 %RH with high accuracy and temperature stability. Voltage efficient humidity sensors generate an output voltage signals in proportion to measuring humidity. In resistive sensing technology, there is a change of electrical resistance due to the humidity detected and they are less sensitive than capacitive sensors. Their change in material properties are also less so more complex circuitry is required. Resistive sensors usually have material properties would need an additional temperature sensor. Within the sensors market, capacitive sensors are more expensive than resistive sensors because they are more expensive to fabricate, however they are more desirable due to the excellent linear response. This means that the amount of water vapour absorbed is proportional to the change in the dialectic constant of the polymer (Ohba, 1992; Chen and Lu,2005; Solomon 2009).

Figure 3.2. Technology for humidity sensors



Key: Humidity sensors may be classified as three types: absolute humidity sensors, relative humidity sensors and dew point humidity sensors (Ohba 1992; Soloman, 2009). Most sensors however are either relative humidity or absolute (moisture) humidity sensors (figure 3.2). Relative humidity sensors are generally used more often and are made from ceramics, semiconductors or polymer material, each with its characteristics and application (Kan-Sen Chou, Tzy-Kuang Lee and Feng-Jiin Liu, 1999). Absolute humidity sensors are also known as hygrometers and may be classified as solid moisture sensors and chilled mirrors hygrometers. This thesis focuses on relative humidity sensors.

Table 3.3: Two types of sensors technologies (Solomon 2009, Honeywell, 2010).

Characteristics	**Resistive polymer sensors (RPS)**	**Capacitive sensors**
Response	Slow response but fast enough for most applications .	Fast response but more expensive than RPS
Temperature range	Suitable for narrower ambient temperature range: -10ºC and 80ºC.	Wider temperature range: -40ºC to over 200ºC.
Humidity Range	15% to 99%	0% to 100%
Accuracy	±2%RH and ±1%RH in narrow ranges.	Small amounts of water can cause a change in sensors capacitance because the water molecule is highly polar.
Composition	Resistive sensors are made up of polymerising an ammonium base solution to a polymer resin base producing a 3D thermosetting resin having good stability.	A thin polymer layer which absorbs water from surrounding is in between two electrodes made from conductive and resistant to corrosion.
Reaction to absorption and desorption	During the presence of humidity ammonium salt in electrode shows conductivity, from the changes in ions. When humidity levels decrease, so will ionization hence decreasing the concentration of mobile ions.	The relative permittivity of water is 80 compared to 2-6 for the polymeric material in the capacitive sensors, making the sensor less prone to interference from other atmospheric gasses.
Measured	Ion movements are measured using the variations in impedance caused by the cell as typically measured in a Wheatstone bridge.	The capacitance of the sensor is determined by the area of both electrodes defined as: $C= (\varepsilon \times \varepsilon_{\circ} \times A)/L$ ε is relative permittivity of polymeric film and $\varepsilon_{\circ}$ of vacuum (8.85×10^{-12} Fm^{-1}). A is the area of electrodes and L is the thickness of polymer film.

3.1.2 iv Sensors choice for this project

The sensors on tables 3.3 and 3.4 were considered and compared in order to choose one that was appropriate for this investigation. The Honeywell sensors were chosen based on the thermo set polymer capacitive sensing element and with a factory fit. The HIH 4000 range of humidity sensors from Honeywell is a humidity sensor with a multilayer sensitive element which protects circuit from dust and oil. It includes alternating polymer layers, coated on a silicon plate containing signal conditioning and multiplication circuit. The HIH 4000 RH sensors can be immediately connected to a microcontroller or other devices that can process a linear voltage signal (chipdip.ru, CJSC, 2010). The high sensitivity to heat suggests that if the sensors would work comfortably when used to measure changes in humidity during prolonged periods of sitting. Due to small variations in temperature this brand of sensors are reported to accurately measure humidity ranges between 0 %RH and 100 %RH with good long term stability. This particular sensor has also been designed to be resistant to contamination and provides fast response (5 seconds) (Honeywell, 2014). An alternative choice was the Sensirion SHT 71 humidity sensors. The SHT 71 resistive humidity sensors are based on non-metallic conductors that change their resistance depending on the water content. A conductor layer is placed between two electrodes and if the conductor absorbs water, the resistance between the electrodes will change (CJSC, 2010).

3.1.3 Introduction to Calibration

The importance of accurate precise measurement of humidity sensors have increased in various fields of industry for the requirements of quality control specifically with traceability to a standard humidity system (Su and Wu, 2004 ; Lin, Yeh, Chan and Chen, 1996). Calibration and testing carried out in laboratories in the UK is based on the ISO standard called 'ISO/IEC 17025: General requirements for the competence of testing and calibration laboratories' (DeSilva, 2002). Accredited measurements in the UK have been developed by the UKAS (member of the National Measurement Partnership) based on the ISO 17025 so that calibration may be traceable (UKAS, 2013). The formal definition for calibration from the ISO 17025 standards is found to be:

"Calibration involves the set of operations which establish, under specified conditions, the relationship between values indicated by a measuring instrument and the corresponding values of a quantity realised by a reference standard"

Table 3.4: Comparison of different capacitive polymer sensors

Device parameter/ Sensor Type	Operating humidities (%RH)	Operating Temperatures	Supply voltage	Accuracy	Stability	Response time	Hysteresis
HTS2030SMD(Measurement Specialities, 2012)	0 to 100	- 60 °C to 140 °C	10 V AC	± 2 % @ 10 to 90 % RH @25 °C	± 0.5 % RH / year	10 s	± 1 % RH
HS1101LF(Measurement Specialities, 2012)	0 to 100	-60 °C to 140 °C	10 V AC	± 2 % @ 10 to 90 % RH @25 °C	± 0.5 % RH / year	5 s	± 1 % RH
HCT01 (Electronik)	0 to 100	-40 °C to +140	5 V AC	± 2 % RH (30...70 % RH) / ± 3 %RH (0 to 90 % RH) (at 30 °C)	< 0.5 % RH / year	6 s	< 1.85 % RH
P14 humidity sensor (Innovative Sensor Technology,2010)	0 to 100	-80 °C to +150 °C	<12 V AC	1.5 % RH (15 to 90 % RH at 23 °C	< 1.5 % RH / year	< 5 s (50 % RH - > 0 % RH)	< ± 1.5 % RH
Vaisala Humicap	0 to 100	-94 °F to +356 °F	10V	± 1 to ± 3 % RH	± 2 % RH over 2 years	8s to 40s	±3.0 %RH
Hygrometrix HMX2200	0.001 to 100	-40 °C to +85 °C	1.25 to 5 V DC	± 1 to 3 % RH	0.2 % RH / year	10 s (from 10 to 90 % RH)	1.7 % RH
Sensirion SHT71	O to 100	-40 °C to 123.8 °C	2.4 to 5.5 V (typ 3.3 V)	±3 % RH	< 0.5 % RH / year	8 s at 63 % RH	± 1 % RH
Michell Instruments H6000 & 6100	0 to 100	-30 °C to +200 °C	2.5 V AC	± 2.5 % RH at 11–90 % RH) @ 23 °C (73 °F)	< 1 % per year	20 s (from 11 to 75 % RH)	0.5 % RH
GE Sensing Technology CC2A25	0 to 100	-40 °C to 125 °C	2.7 to 5.5 V	± 2 % RH (20 to 80 % RH)	< 0.5 % RH / year	7000 ms (25 °C)	± 2.0 % RH
MaxDetect Technology Ltd. RHT03	0 to 100	-40~80 °C	3.3-6 V DC	± 2 %RH(Max ± 5 %RH);	± 0.5 % RH / year	50 µs	± 0.3 % RH
Honeywell HIH-4000-004	0 to 100 non-condensing	-40 °C to 85 °C	4.0 V DC to 5.8 V DC	± 3.5 % RH, 0-100 % RH non-condensing, 25 °C, 5 Vdc supply	± 0.2 % RH/ year	5 s in slowly moving air at 25 °C	± 3% of RH Span Maximum

In order to correct the deviation, a measurement result can be related to a reference through a documented unbroken chain of calibrations, each contributing to the measurement uncertainty (NPL, 2012). According to the ISO 10012-1:1992: traceability is defined as:

“The property of the result of a measurement standard, generally international or national standard, by an uninterrupted chain of comparisons”.

Calibration usually certifies the outcome in a report, stating the instrument errors, any corrections applied and the uncertainties that exist in measurements (Parker, Geoffrey, Wilson, Szarka et al., 2010).

3.1.3i Calibrating humidity measuring instruments

More companies are facing the need to calibrate their humidity sensors accurately and efficiently in order to ensure that the production output is consistently of the same quality (Heinonen, 1996; Lu and Chen, 2007). Calibrating humidity sensors is a challenging task with many complexities and techniques that need to be understood (Su and Wu, 2004; Lin, Yeh, Chan and Chen, 1996). This requires specialist knowledge of the discipline and its systems (Lu and Chen, 2007). There are a variety of RH instruments available such as the RH sensors (capacitive and resistive) however their accuracies are of concern (Lu and Chen, 2007). RH sensors usually fall within the limits of ± 1 to 4 %RH which is much stronger than the accuracy of the horse hair hygrometers at ± 10%. However even with this specified performance, calibration errors can render any equipment output to be inaccurate. This suggests that the standard of calibration needed must be incredibly accurate in order to meet the smaller accuracies which is required when using RH sensor technology in particular. All RH sensors require calibration to a high standard, not only at the production phase but as part of the ongoing maintenance to correct for any drift in measurement (Veriteq, 2002). According to the International standards on the ‘Guide to the Expression of Uncertainty in Measurement’ (ISO GUM) the uncertainty of humidity sensors testing may be evaluated by deducing the equations of measurement and evaluation sources of uncertainty (JCGM, 2008; SU and Wu, 2005). Uncertainty evaluation is also widely adopted for sensor analysis on uncertainty and found to be useful (Chen and Lu (2007). The main objective of calibration is to ensure the accurate type of humidity measurement can be carried out in the right equipment with proven processes that allow the achievement of consistent results that are repeatable with thermal stability and uniformity (Veriteq, 2002). The calibration device for relative humidity sensors would include characteristics of accuracy, inexpensive, quick, easy to operate and highly reliable. It is therefore suitable that sensors be calibrated (in laboratory conditions) in a consistent and stable environment one that would prevent temperature fluctuations and moisture ingress. To ensure accuracy in the sensors chosen for this study (HIH-4000-004) a calibrated climatic chamber was the chosen device for calibration. Climatic chambers provide controlled internal environments for humidity and temperature in a sealed area. This ensures that the sensors can be reliably calibrated and traced to national standards.

3.1.3ii Function of the climatic chamber

The climatic chamber (The Design Environment Ltd.) is a temperature and humidity chamber for which settings may be chosen and stabilised within a sealed controlled environment. This chamber (serial number 01-94-1705 and model FS990-40V) was originally only a temperature chamber with a vibration interface. Humidity system was installed 10 to 12 years ago by the company. For maintenance of the chamber the company advices calibration should be carried out once a year (Appendix 2c: calibration certificate). The distribution of humidity within the chamber is reported to be fairly good. Initially when the temperature and air are changing direction in the chamber, there may be a discrepancy where the humidity outlets may be warmer or cooler or less or more humid. After 30 minutes to 45 minutes, the distribution is constant throughout the chamber. There is a water tank which gets warmed up (electric heaters in the tank) and the warm humid vapour that is released (from tank) gets sent into the chamber through an inlet pipe and then into the chamber with the help of a fan (right side of the chamber) (Heinine, 1996; Su and Wu, 2004). The water is drawn back into an outlet pipe (left side of the chamber) using another fan which brings the water vapour back into the tank. There is a capacitance probe 12 mm diameter located next to the temperature probe on the left side of the chamber. The capacitance probe checks the capacitance in the chamber air. Low humidity means low capacitance for example. The Programmable logic controller (PLC) communicates these values (The Design Environment Ltd, 2012). For the temperature side a PT100 resistance thermometer probe responds to the controllers command (required temperature) and feeds back the information to the controller (in a loop) until the controller setting matches the probe reading. The chamber heats up and cools down using a heating element and a fan (right side of chamber). The capacitance probes (Vaisala, 2010) within the chamber are calibrated against saturated salt solutions in cylinders for the following humidity values, 11 %RH, 33 %RH, 53 %RH, 75 %RH and 90%RH (Novasina humidity standards SAL-SC, 1977). The probes are placed on top of the jars and left for an hour to stabilise. The salts have an accuracy of +/- 0.3 % RH. Once the probes are calibrated successfully the humidity standards are also available with an official certificate of an accredited calibration laboratory. The probe used is a PT100 resistance thermometer (left side of chamber). The chamber is run at temperatures determined by the customer for the purpose of application. Probe is placed next to chamber probe and left to stabilise at each of the four levels for 1 hour. There will be a 0.3-0.5 ^{o}C discrepancy which is within tolerance.

3.1.4 Study outline

Since sensors are the key method of measuring the skin at the seat interface, research into their reliability and characteristics are important elements to study. This study will address the characteristics and limits of the humidity sensor and the seat material combination. The emphasis will be learning more about this combination and ensuring the limits of capability of the measurements are not influencing that which they purport to measure. This extends from the study by McCarthy et al., (2009) where the reliability and characteristics of the sensors were studied. Therefore to explore this research area it would be useful to carry out studies by replicating and testing a previous study carried out on an experimental basis with new data. Specifically this chapter will replicate aspects of a sensors seat cover study to understand the range of detection (Cengiz and Babalik 2007; McCarthy et al., 2009) and to verify the reliability and accuracy of the sensors in relation to manufacturer's specifications. It will also demonstrate the suitability of using humidity sensors to study the interface between a subject and sitting surface. Please refer to Table 1.1 for the aims, objectives and research questions of this chapter. The subsequent methodology section will provide information on how the sensors were prepared for calibration followed by the analysis of studies.

3.2 Methodology and results: sensor verification experiments

This section describes the preliminary experiments on the humidity measurement system to prepare for the five main experimental studies (analysis tools IBM SPSS Statistics 20).

Preliminary testing (MS Excel):

- Characteristics of the humidity measurement system
- Preparation for calibration tests
- Calibrating the humidity sensors
- Regression factor analysis
- Calibration of the temperature sensors

Experimental studies and the research design is on Table 3.5.

Table 3.5: The research design of Chapter 3.

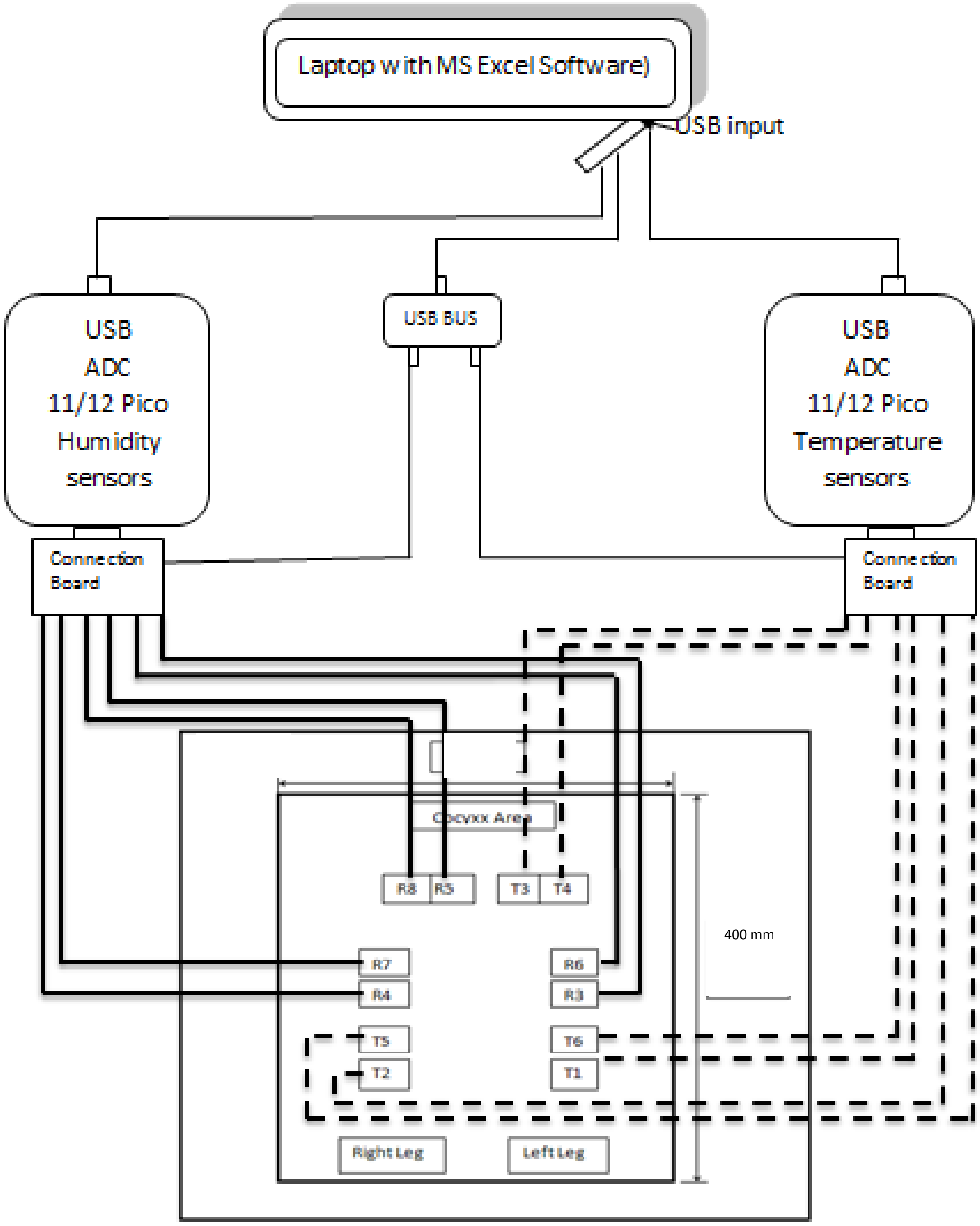
Study	Title	Aim	Research question	Hypothesis (H_0)	Statistical analysis
1	Comparing the performance of existing and new sensors	To find out if the performance of new sensors differed to an existing set used over 2 years (publication)	Would sensors with 2 years of usage perform different to brand new sensors?	There is no difference between the existing and new sensors.	The data from both existing (used) and new sensors (continuous data; less than 2000 data points) were found to be normally distributed (p > 0.05; Shapiro-Wilks) therefore parametric analysis was used. The independent samples t-test was used because it allows the comparison (of continuous variables) of the mean scores of two different groups. The assumptions for the independent samples t-test is that it is a technique used when two groups are different (existing and new sensors) or independent. This test will indicate whether the existing sensors differ from the new sensors in relation to there output in proportion to and in relation to the relative humidity.
2	Sensor verification experiment after exposure to desiccant	To investigate the accuracy of sensors using a drying technique from a published methodology to compare this to the same sensors before drying through calibration.	Would sensors perform differently after exposure to a desiccant?	There is no difference between the new sensors before and after drying them.	Paired samples t-test (repeated measures) was used to investigate the changes in mean scores for the same set of sensors tested before and after drying. The output data samples were found to be normally distributed (p > 0.05: Shapiro-Wilks) therefore a paired sample t-test, parametric test was chosen. The assumptions for the paired samples t-test is that samples are related because the same sensors were tested each time.
3	Endurance of humidity sensor with respect to time and location	To investigate the decay properties of the sensors with respect to time and location.	Would the performance of brand new unused sensors deteriorate over time and would location affect their ability to measure over time?	1) There is a difference between sensors in different locations. 2) There is a difference between sensors measured over 7 months.	Data from both the existing (used) and new sensors were found to be normally distributed (p>0.05; Shapiro-Wilks) therefore parametric analysis was used. The study required two statistical tests to be carried out. Test one: The one-way repeated measures ANOVA test to compare one sensor at one location between months zero and six, allowing the determination of each sensor's performance over a timeline. Test two: the one-way between-groups ANOVA, was used to test sensors at all locations at each individual month. Post hoc tests were used to determine where differences may lie.
4	Material comparison for encapsulating sensors	To observe how sensors measure the same environments through a variety of different materials.	Is there a suitable material that can protect sensors and allow them to make reliable measurements?	There is no difference between a sensor measuring with no cover and through a variety of materials.	Data from the sensors was not normally distributed (p<0.05;Shapiro-Wilks) therefore non-parametric analysis was used. The Wilcoxon signed rank test was chosen because the sensors were measured on two different occasions: the sensors with no cover and any one sensor with a material covering.
5	Sensitivity of sensors on water detection	To find out measuring sensitivity and proximity of sensors.	Are the sensors able to detect moisture at different proximities?	1) There is no difference when sensors measure ambient air. 2) There is no difference when water drops are introduced.	Data was normally distributed (p > 0.05; Shapiro-Wilks). A paired samples t-test was chosen because a comparison of the same sensors under two different conditions was required: uncovered sensor compared to sensors having had water drops introduced. This test will indicate whether there is a statistically significant difference in the mean scores for the two conditions. This complies with the assumptions for the paired samples t-test where the same sensors are used on both conditions.

3.2.1 Characteristics of the humidity measurement system

For this study humidity sensors, model: Honeywell HIH 4000-004, purchased in 2010 were embedded in a contoured foam seat cushion. Figure 3.3 shows how these humidity sensors were set-up to a humidity measurement system. Six humidity sensors were connected to an analogue to digital convertor (ADC) called a 'Pico 11/12 module' and a further six temperature sensors to a second ADC of the same model. Each ADC system, (Pico ADC-11/12 (Pico Technology, St Neots, Cambridgeshire, UK) has an eleven channel ADC interface with 12 - bit resolution along with 1 kHz sampling frequency per channel. Advantages of the system included an anologue input range from 0 to 2.5 V, a sampling rate of 20 kS/s and it is able to be powered directly from the personal computer. For this study, each Pico ADC convertor had only 6 inputs occupied (six humidity and six temperature sensors). The extra channels could be used in the future for other measurements such as pressure. A Microsoft Visual Basic software with a user friendly interface developed in the McCarthy et al., (2009) study was used to relay the data. This software enabled device initialisation, real-time data storage, off-line analysis and graphical display. It also allowed real time data collection to be stored into a MS Excel spreadsheet which could be saved for later analysis.

Each humidity and temperature sensor was set up as a circuit to a small sized board of 20 x 15 mm which was embedded in cut out recesses in the cushion (dimensions 20 mm width, 30 mm length and 20 mm depth) to accommodate the sensors. There were twelve recesses in total. The author soldered all the humidity and temperature sensors to the small boards using the design specifications from the McCarthy et al., (2009) study. Figures 3.4 a and 3.4 b show the cut out locations which are located around the sitting interface (left thigh, right thigh and coccyx). The foam seat cushion is contoured so that when seated it supports the body contours of the individual (Invacare ltd., 2010). This promoted stability in a controlled seating area where the sensors were embedded. In the sitting experiments in chapter 4, this allowed the person to be measured in a repeatable location across many human subjects.

Figure 3.3: Schematic diagram of the humidity measurement system



Key: Both sets of humidity sensors (labelled as R3, R4, R5, R6, R7 and R8) and temperature sensors (labelled as T1, T2, T3, T4, T5 and T6) were embedded in the foam seat cushion (400x400x120 mm) although only the humidity sensors were analyzed. The sensors were labelled according to the corresponding channel numbering system on the ADC through the connection board. A single USB (Universal Serial Bus) port was employed as the power supply for the entire measurement system. The USB specification allowed a 5V (voltage) supply on a single wire which was compatible with the requirements of the HIH4000-004 sensors. The USB bus connector increased transportability and was used to prevent errors in the connection to the power supply. USB is normally suitable for digital circuits and not analogue however to overcome this, high resolution power source may be used in future. The multichannel nature of the USB bus connector meant that more than one humidity measuring system could be run parallel which was useful in chapter four when simulataneous sitting profile data was collected.

3.2.2 Preparation for calibration tests

For calibration purposes, it was envisaged that maintaining the sensors embedded in the foam cushion might allow them to remain in a consistent position and limit any movement due to the air movement. When sensors were removed from the cushion and placed in the sealed chamber, the draft currents in the climatic chamber appeared to cause a lot of movement in the sensors. At the time of it was not known whether this could affect the measuring ability or damage the circuitry of the sensors which were small and delicate. Therefore to ensure fairness in the methodology, the author compared these two conditions by calibrating the sensors when embedded in the foam seat cushion and then out of the cushion. The sensors giving the best and most stable output signal would be used for further analysis in particular for the regression analysis. Figure 3.5 shows the difference between these two conditions. Table 3.6 displays the statistical differences between the two conditions and their proportional constant. The signal labelled ‘average sensors-not in foam’ is the average reading of four humidity sensors. There were six sensors however two sensors needed re-soldering. Once re-soldered, the same six sensors were used to get the average signal labelled ‘average sensors- embedded in foam seat’. To assess the two signals above a simple regression analysis (also known as the curve fitting equation) was used to obtain the ‘line of best fit’ for the series of data. Usually this curve fit produces an equation that may be related to any points on the line or curve. Using regression analysis may sometimes be helpful for smooth data and remove noise. Figure 3.5 shows both signals that have a linear relationship. In order to find out how well linearly correlated the x-y data points are, the r^2 method was used.

Figure 3.4. Set up of sensors during calibration in the climatic chamber

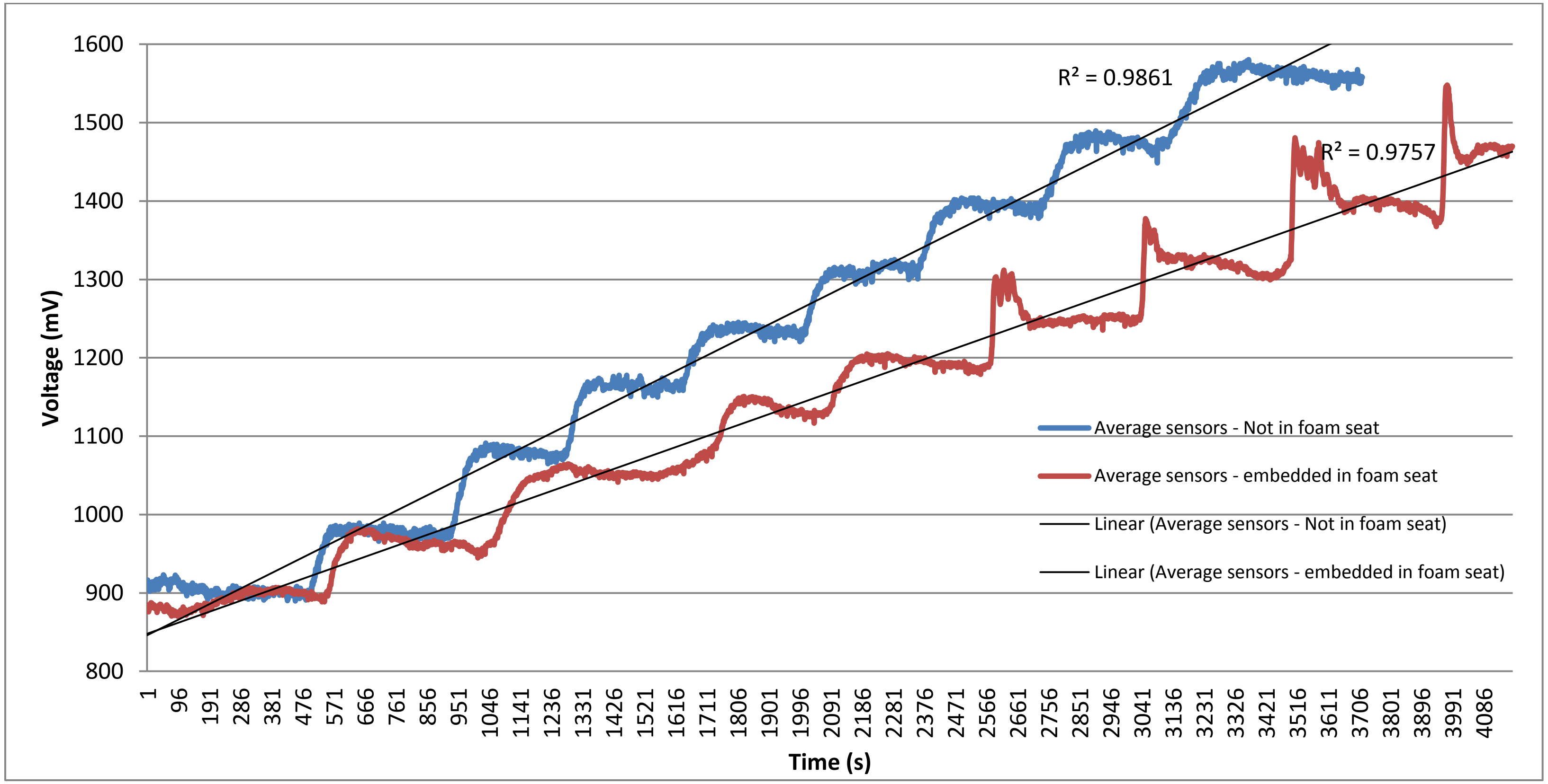
a. sensors in cushion

b. sensors in chamber

c. ADC and laptop.

Key: The embedded sensors and cushion (figure 3.4a) were then placed in the humidity chamber for calibration (figure 3.4b). The foam seat cushion is a component of a modular seating system called 'Flotech Solutions' provided by the wheelchair and cushion manufacturer MSS-Invacare (seat dimensions: 400 mm x 400 mm on Figure 2). It is made from 'high density combustion modified high resilience foam' or CMHR (Invacare Corporation, 2010). The foam is highly resilient due to its less uniform cell structure which gives it high support, allowing it to return to its original state after weight is removed (Polyurethane Foam Association, 2000). Both ADC's were connected to the laptop so that data could be collected and stored on a Microsoft (MS) Excel file (figure 3.4c).

Figure 3.5: The average signals of sensors in two separate conditiones when calibrated in the climatic chamber at 25◦C between an ascending humidity scale of 30 %RH to 70 %Rh with 5 %RH increments.



Key: Figure shows both signals that have a linear relationship. In order to find out how well linearly correlated the x-y data points are, the r^2 method was used.

Table 3.6: Proportional constant between signals.

Sensors not in foam (y)	Sensors embedded in foam (x)	Proportional constant (dy/dx)
899.8 (30.1 %RH)	900.6 (30.2 %RH)	1.00
974.7 (35.1 %RH)	960.1 (34.1 %RH)	1.01
1085.5 (42.5 %RH)	1051.3 (40.2 %RH)	1.03
1166.2 (47.9 %RH)	1132.2 (45.6 %RH)	1.03
1239.5 (52.8 %RH)	1190.8 (49.5 %RH)	1.04
1318.8 (58.1 %RH)	1251.2 (53.6 %RH)	1.05
1395.9 (63.2 %RH)	1329.3 (58.8 %RH)	1.05
1474.7 (68.5 %RH)	1401.9 (63.6 %RH)	1.05
1566.5 (74.6 %RH)	1461.8 (67.6 %RH)	1.07

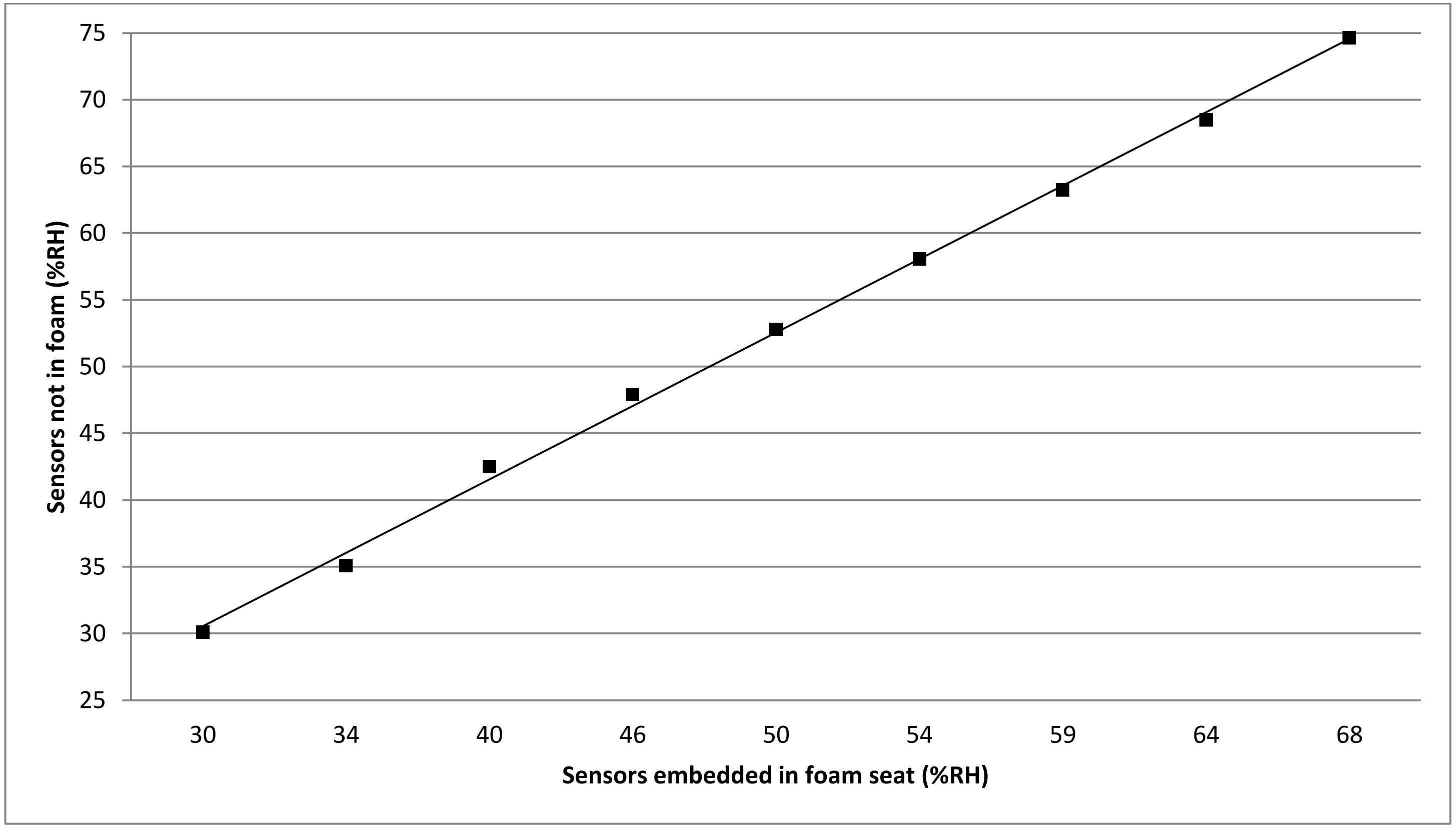
Key: displays the statistical differences between the two conditions and their proportional constant. The signal labeled 'average sensors-not in foam' is the average reading of four humidity sensors.

The simple regression R^2 (also known as coeffricient of determination) is a technique used to indicate if the explanatory terms in a model is linearly correlated, and in which direction it's correlated. The R^2 calculates an equation that minimizes the distance between the fitted line and all of the data points. In general, a model fits the data well if the differences between the observed values and the model's predicted values are small and unbiased. The R^2 values that are closer to 1 means that it is a good linear fit. Less than 0.5 means that the model may not be working in the environment it is studied in. According to figure 3.5, the sensors not in the foam seat give a better fit with a result of 0.9861 however when the sensors were embedded in a seat it was only slightly less at 0.9757. As both the results are close to 1 it means that both the signals have a good fit however for a fair test the signal from the sensors not in a foam seat was used because the R^2 was slightly better. From visual observation the raw data on figure 3.5 show a small difference between the two average signals between points 30 %RH and 40%RH. After this the sensors embedded in a foam seat rise slower than the sensors not embedded in a seat. A less statistical method of finding out linearity is by computing the proportionality of the x-y line. The results on table 3.6 show the statistical difference between the two signals and the proportional constant showing linearity. Figure 3.6 shows the proportional relationship between the sensors embedded in the cushion and when not embedded.

Investigating the signal output

The humidity sensors (HIH4000-004, Honeywell, 2012) can provide near linear voltage output, has a low power design, fast response time (5 seconds) and low drift performance (Honeywell, 2012). The general specifications of the HIH4000-004 are listed on Table 3.7. Based on these parameters the only difference between the HIH4000-004 used in this study and the HIH4000-001 humidity sensors used in the McCarthy et al., study (2009) is the response time. The response time for HIH4000-001 is 15 seconds.

Figure 3.6: Average plateau signal at the epoch points.



Key: The graph shows the average plateau signal at the epoch points for the sensors when not embedded in the foam and embedded in the foam during humidity calibration in the climatic chamber between the humidity of 30 %RH and 70 %RH at 5 %RH increments.

Table 3.7: Specifications of the HIH4000-004 (Honeywell, 2012).

Parameter	***Value***	***Unit***
Hysterisis	3	% RH
Repeatability	± 0.5	% RH
Settling time	70	ms
Response time	5	s
Stability (at 50% RH)	1.2	% RH
Voltage supply	4 – 5.8	V
Operating temperature	-40 - 85	º C
Current supply	200 - 500	uA

Key: Based on these parameters the only difference between the HIH4000-004 used in this study and the HIH4000-001 humidity sensors used in the McCarthy et al., study (2009) is the response time (15 s)

Since the humidity sensors output a voltage signal, the corresponding humidity equivalent value would need to be calculated in order to understand the signal in terms of the environment. Referring to the manufacturer's datasheet on Table 3.8, it is possible to use a ratio metric response to convert this voltage output signal into a humidity equivalent value, for the ranges 0 %RH to 100 %RH. ('%RH' is the expressed unit of relative humidity used throughout this chapter). Observing the zero offset from Table 3.8, the voltage output at 0 %RH is 0.839 V. By taking the linear output for 3.5 %RH (accuracy at 25˚C), the slope of 30.24 mV / %RH may be used to convert voltage into percentage humidity using the following equation:

RH = (Vout – Zero offset) / slope **(Equation 1)**

When the values are substituted the equation is as follows (from table 3.9):

RH = (Vout – 0.839V) / 30.245 (V / %RH) **(Equation 2)**

When the sensors measure the humidity levels in the climatic chamber, it is expected that all the humidity sensors would follow any humidity change perfectly. This perfect signal is referred to in this study as the 'expected sensor output'. This may be calculated by finding the voltage difference between the 0 %RH and 75.3 %RH (Table 3.8) and then dividing this new voltage by the humidity steps between them which will result in the voltage value for 1 %RH. For every 1 %RH humidity, there is a voltage value of 0.03024 V/%RH. This voltage value may be multiplied with any humidity level in the climatic chamber (for example at 30%RH) to obtain this 'expected sensor output'. So if the climatic chamber was set to a humidity level of 30 %RH and if the sensors were perfect, it should ideally output a voltage value signal of 907 mV (Table 3.9).

This technique was used because the climatic chamber used for calibration did not output a voltage signal corresponding to humidity signals. Since the climatic chamber was traceable to national standards, the author decided that this technique would be appropriate so that the raw output signals from the sensors could be understood in voltages. In reality the sensors will not measure as the 'expected output voltage' and this will be investigated in the next section. If this is the case, it may be possible to incorporate a correction factor to bring the voltage signal up to the 'expected output voltage' which is traceable to national standards.

Table 3.8: Manufacturer information for humidity sensors HIH-4000-004 Honeywell.

Model	HIH-4000-004
Channel	426
Serial number	20114300383
Wafer number	02682 E18
MRP number	8921769 Calculated Values at 5 V
V_{out} at 0 %RH	0.839263 V
V_{out} at 75.3 %RH	3.116677 V
Accuracy at 25 $℃$	3.5 %RH
Zero offset	0.839263 V
Slope	30.244545 mV/%RH
Sensor RH	(V_{out}-0.839)/ 30.25 Ratiometric response for 0 to 100 %RH
V_{out}	$V_{supply(0.168\ to\ 0.773)}$

Table 3.9: Humidity calculation for the expected sensor output.

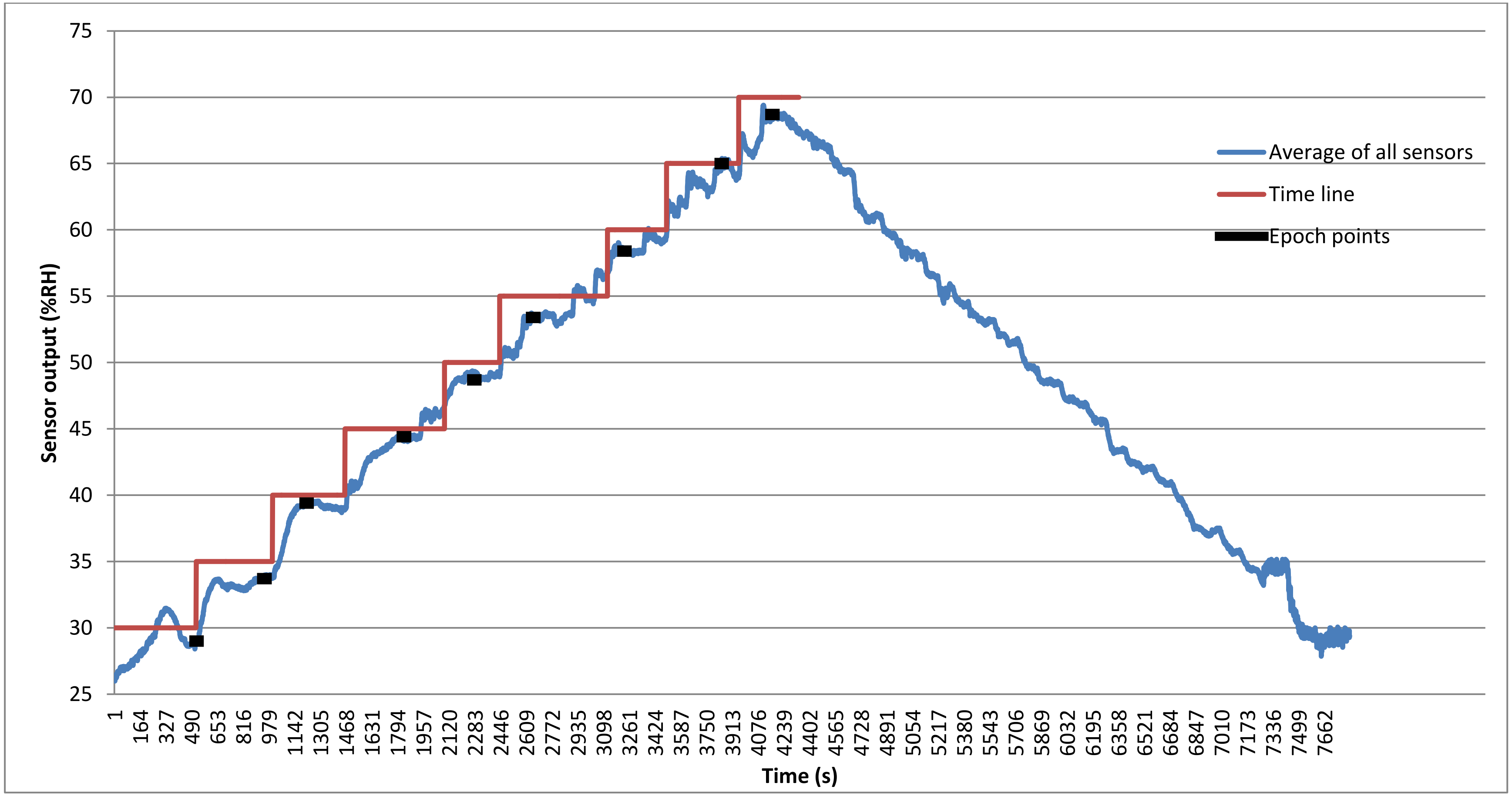
Humidity values (%RH)	Humidity to voltage conversion (V)	Expected sensor output (mV)
30	30 x 0.03024 = 0.907	907
35	35 x 0.03024 = 1.058	1058
40	40 x 0.03024 = 1.209	1209
45	45 x 0.03024 = 1.360	1360
50	50 x 0.03024 = 1.512	1512
55	55 x 0.03024 = 1.663	1663
60	60 x 0.03024 = 1.814	1814
65	65 x 0.03024 = 1.966	1966
70	70 x 0.03024 = 2.117	2117

Key: For every 1 %RH humidity, there is a voltage value of 0.03024 V/%RH. This voltage value may be multiplied with any humidity level in the climatic chamber (for example at 30%RH) to obtain this 'expected sensor output'.

3.2.3 Calibrating the humidity sensors

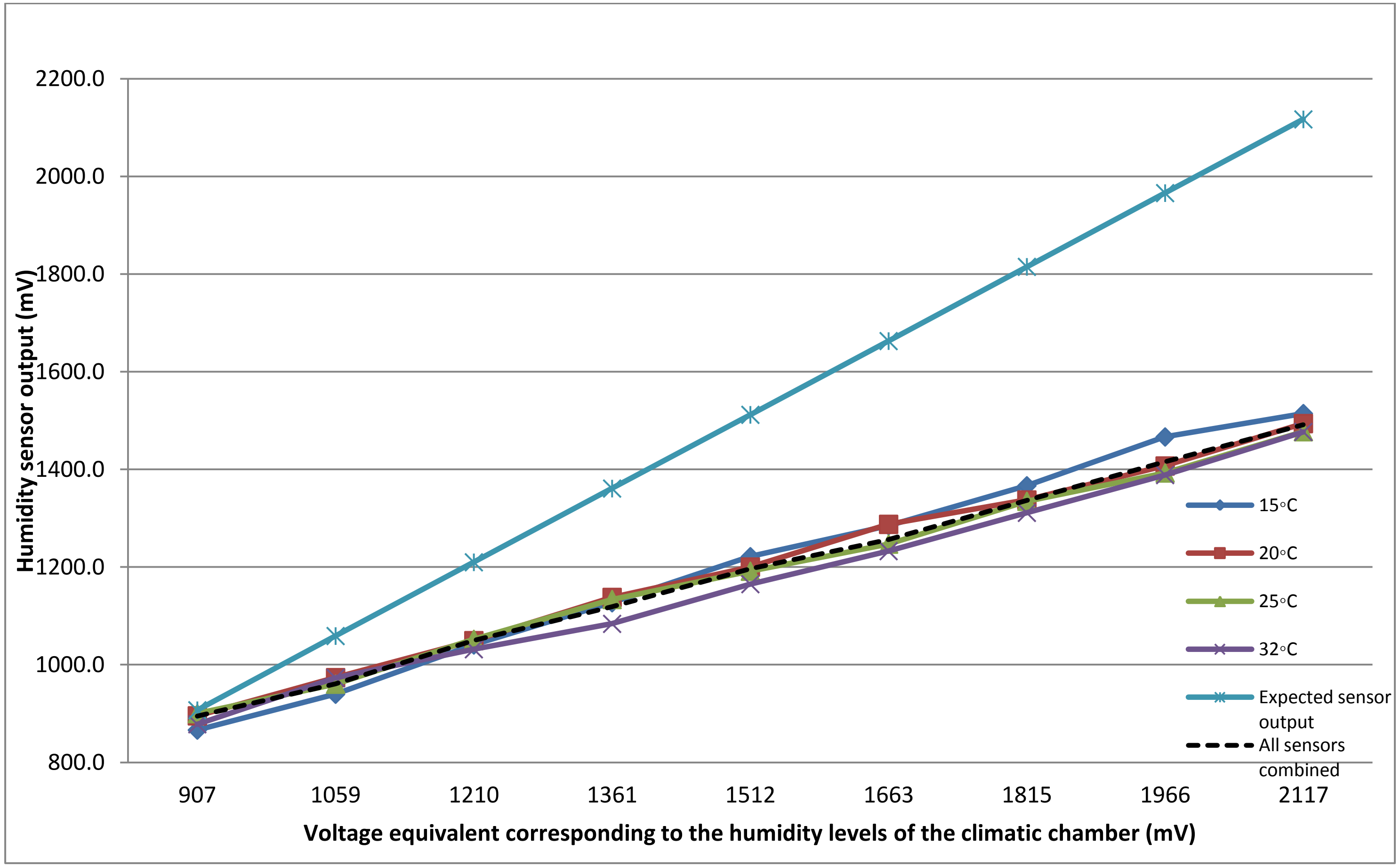
The signals of six HIH4000-004 humidity sensors were compared to the climatic chamber settings (FS990-40V serial number 01-94-1705, The Design Environment Ltd, Ebbw Vale, UK; Certificate No. 6557 in appendix 2c). The climatic chamber was set to a humidity profile containing ascending and descending humidity levels between 30 %RH and 70 %RH with 5 %RH incremental steps. The humidity profile was set to four different temperatures (15 °C, 20 °C, 25 °C and 32 °C). Each incremental step was left to stabilise at 10 minutes. Prior to calibration the climatic chamber measured for 30 - 45 minutes to allow the sensors to come to an approximate thermodynamic equilibrium. The output signals from the sensors included a lot of noise and so the moving average methodology was implemented at each step to reduce this. The moving average is commonly used in a time series and is a calculation which analyses a set of stable data points (epoch points) by averaging it. Across the ascending humidity profile in figure 3.7, each humidity step was averaged across the straightest or most stable portion of the output line (across a 20 seconds epoch time range) within the 8 to 10 minute increments. Figure 3.7 is an example of how this analysis was carried out. It shows the average response of the sensors so that the epoch times may be seen. As an example the blue line on figure 3.7 indicated as 'all' represents the combined average of six humidity sensors when in four different temperature settings in the climatic chamber to demonstrate the application of the epoch points. Therefore the 'all' output is a result of 24 measurements averaged. The arithmetic means and standard deviations (from the 20 points epoch sites) of the six sensors tested in the climatic chamber are shown on Table 3.10 and visually represented on Figure 3.8. Figure 3.8 also presents the difference between the mean sensors and the climatic chamber humidity levels. The humidity profile was set to 25 °C because it was used in the manufacturer's data sheet on calibration on Table 3.8. However the author decided to test the humidity profile at all four temperatures in order to identify that the sensors output in the 25 °C environment was the best to analyse in (Connolly et al., 2002). This was done by using regression analysis to see if the average signal outputs were linear (Figure 3.9). The regression analysis for the R^2 scores for the four temperatures are shown on Table 3.11. The R^2 values that are closer to 1 means that it is a good linear fit. Less than 0.5 means that the model may not be working in the environment it is studied in. According to figure 3.9 and table 3.11, the average sensor output in all four temperatures are closer to 1 which means they are all good fits. However at 20 °C and 25 °C they are slightly better. The results here indicate that the 20 °C has the best fit however for consistency with the calibration tests used by the manufacturer (Table 3.8), the 25 °C environment will be used for analysis.

Figure 3.7: Average of all sensors outputs when measuring the humidity chamber.



Key: The time line steps in the diagram demonstrates the time periods that each incremental level was stabilised at (8 to 10 minutes). The epoch points are 20 seconds samples at the most stable portion of each incremental level.

Figure 3.8: Actual versus expected sensor output of sensors in mV at different temperatures



Key: This figure displays the averaged epoch points for each humidity level according to the four chamber temperatures. This is compared to the expected sensor output (to represent the output from the climatic chamber).

Table 3.10: The voltage signal output of the six sensors measured at the incremental humidity levels (represented in voltage) across four temperatures.

Expected sensor output/Climatic Chamber setting (mV) with equivalent humidity levels	15◦C			20◦C			25◦C			32◦C			Combined mean of 6 sensors at 4 temperatures.		
	Voltage output (mV)														
	Mean	*SD*	*Absolute Error*	*Mean*	*SD*	*Absolute Error*	*Mean*	*SD*	*Absolute Error*	*Mean*	*SD*	*Absolute Error*	*Mean*	*SD*	*Absolute Error*
(30 %RH) 907	866.4	5.2	-40.6	895.5	2.7	-11.5	900.2	1.7	-6.8	878.3	3.1	-28.7	894.8	1.7	-12.2
(35 %RH) 1059	939.8	1.8	-119.2	973.8	2.8	-85.2	960.4	2.2	-98.6	973.1	3.8	-85.9	960.7	1.3	-98.3
(40 %RH) 1210	1040.7	3.1	-169.3	1049.5	2.5	-160.5	1052.3	2.1	-157.7	1031.9	3.5	-178.1	1049.7	0.7	-160.3
(45 %RH) 1361	1127.1	1.5	-233.9	1138.1	3.4	-222.9	1133.8	2.3	-227.2	1083.9	3.6	-277.1	1119.0	1.8	-242.0
(50 %RH) 1512	1221.5	3.3	-290.5	1200.2	3.1	-311.8	1191.7	3.5	-320.3	1165.2	6.1	-346.8	1196.4	1.3	-315.6
(55 %RH) 1663	1285.0	1.7	-378.0	1287.7	3.7	-375.3	1247.2	1.8	-415.8	1232.8	5.1	-430.2	1256.1	3.6	-406.9
(60 %RH) 1815	1366.7	1.8	-448.3	1337.6	1.5	-477.4	1334.9	5.1	-480.1	1311.3	2.1	-503.7	1336.6	1.4	-478.4
(65 %RH) 1966	1466.7	3.0	-499.3	1407.2	2.9	-558.8	1392.9	2.6	-573.1	1388.6	2.8	-577.4	1415.3	9.0	-550.7
(70 %RH) 2117	1514.5	3.7	-602.5	1494.0	7.1	-623.0	1477.5	0.4	-639.5	1476.9	3.6	-640.1	1491.7	11.5	-625.3
Average error			**-309.1**			**-314.0**			**-324.3**			**-340.9**	**(SD) 210.5**		**-321.1**

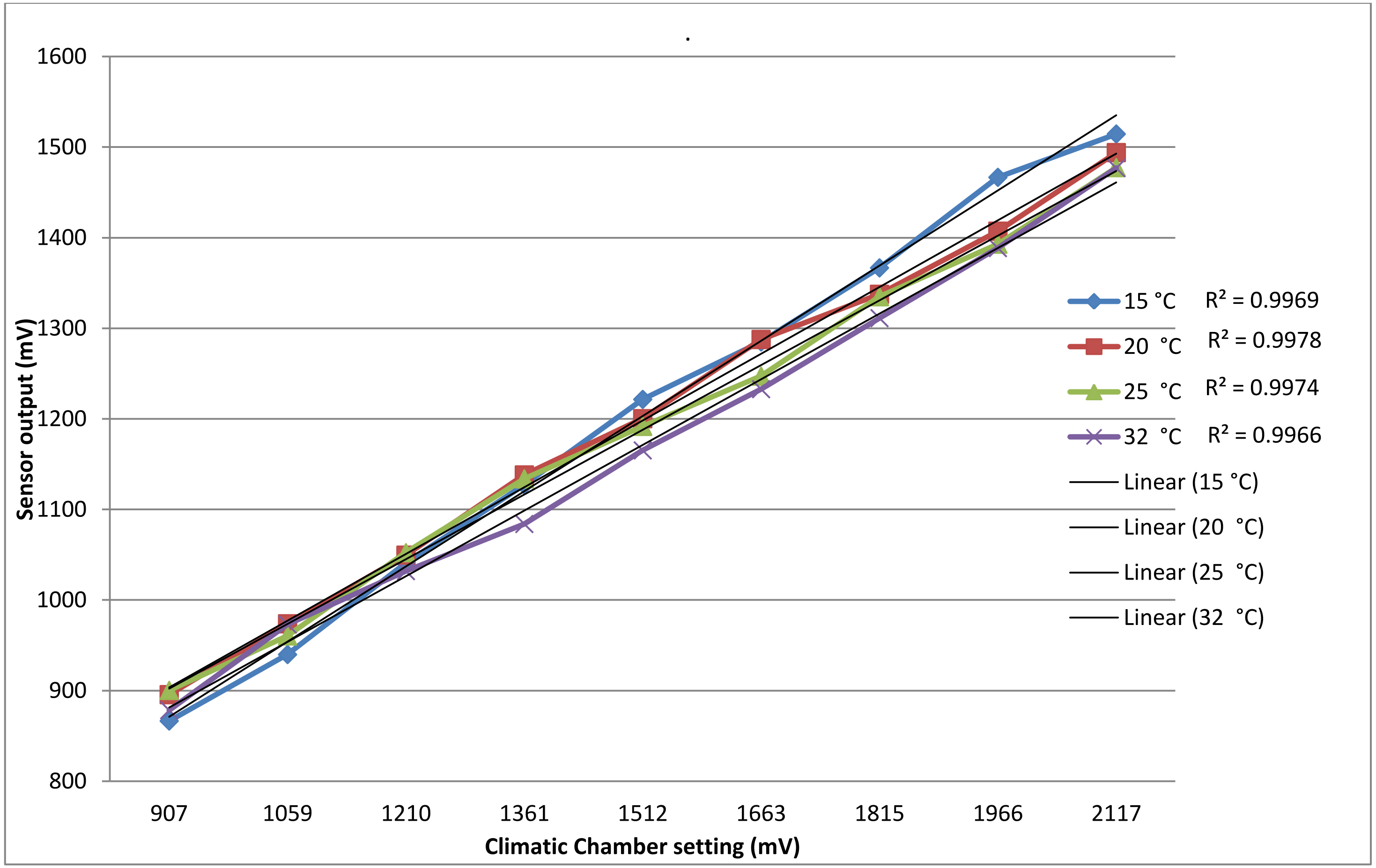
Key: The arithmetic means of each of the 6 sensors at the respective 4 temperatures are shown above. This table is represented in figure 3.8.

Table 3.11: The regression analysis scores

Temperatures	Coefficient of determination R^2 result
15 °C	0.9969
20 °C	0.9978 (closest to 1)
25 °C	0.9974 (closest to 1)
32 °C	0.9966

Key: the average sensor output in all four temperatures are closer to 1 which means they are all good fits (Thomas, Nelson and Silverman, 2005).

Figure 3.9: Regression analysis for the average sensors at four temperatures



3.2.4 Regression factor analysis

During calibration the sensors consistently measured below the climatic chamber setting (or in voltage relation: below the expected sensor voltage) and although this did not mean that the sensors were out of calibration. The main reason for these differences was the sensors have been attached to the circuit board and as a result the wire connection, soldering and sensor placement will affect the outcome. This is called system error (usually higher than datasheet information). This difference may be amended by using a curve fitting (or polynomial approximation) algorithm. Another explanation is that HIH-4000-004 sensors provide analogue output (voltage) and therefore it is very sensitive to the ambient environment (especially to moisture). To overcome this, a filter could be used to remove noise (for example a moving average filter to the raw data as explained earlier). For more reliable measurement digital sensors would be an optimal solution although this is not explored in this study. However the ADC's allowed the data to be presented digitally.

As the climatic chamber was traceable to national standards, it was important to ensure that the humidity sensor's actual signals matched the settings of the climatic chamber. As explained earlier, the climatic chamber only outputs a humidity value (in %RH) therefore it was converted to a voltage equivalent (referred to as the 'expected sensors output') so that the actual sensor output's difference may be understood. This conversion is explained in the section above titled, 'Sensor output'. Using the first order of polynomial fitting which is a linear equation, the LMS (least mean square) solution was used to find the optimal coefficients to amend the actual sensor signal. In order to study and amend the data of the actual sensors, they were measured in the climatic chamber at nine ascending humidity levels between 30 %RH and 70 %RH at 5 %RH increments. This data is referred to as the 'actual sensor output'. The calculation for this section can be found in the MS Excel sheet in Table 3.14. The scatter graph on figure 3.10 show the average of six humidity sensor's 'actual sensor output' (y-axis) compared to the 'climatic chamber levels' in relative humidity (x-axis). To calculate this linear regression equation using the least squares criterion, the x-y axis was assigned and calculated as follows (Lu and Chen, 2007). Figure 3.10 shows on the x-axis the humidity levels of the climatic chamber (in %RH) and on the y-axis the measured signal (actual sensor signal) which produces a linear line. Therefore based on the data Appendix 3d, the equation of the linear line may be found. This equation will relate the actual sensor output to the climatic chamber settings.

y= **actual sensor output (mV)**

x= **climatic chamber levels (% RH)**

Using the statistical equation for y, the following were found based on the data in Table 3.14.

$y = b_O + b_1 x$ (where b_1 = slope and b_O = y intercept; n=data points and in this study there are 9)

$$b_1 = \frac{\sum xy - \frac{\sum x \cdot \sum y}{n}}{\sum x^2 - \frac{(\sum x)^2}{n}}$$

$$b_1 = \frac{578853.3929 - 554462.5}{24000 - 22500} = \mathbf{16.26059527}$$ **(This is the slope of the linear model)**

$$b_O = \frac{\sum y - (b_1 \cdot \sum x)}{n} = \mathbf{419.1091}$$ **(This is the Y-intercept)**

Therefore the equation for the linear model is as follows:

$y = b_O + b_1 x$

$y = 419.11 + 16.261 x$ **Equation 3**

The actual voltage output (V_{out}) by the sensors may now be converted to relative humidity using equation 3. This equation will also adjust the converted relative humidity so that it relates to the climatic chamber levels (x-axis). To do this equation 3 may be manipulated as follows:

$Y (V_{out}) = 16.261 x + 419.11$

$V_{out} - 419.11 = 16.261 x$

$$X (\%RH) = \frac{Vout - 419.11}{16.261}$$

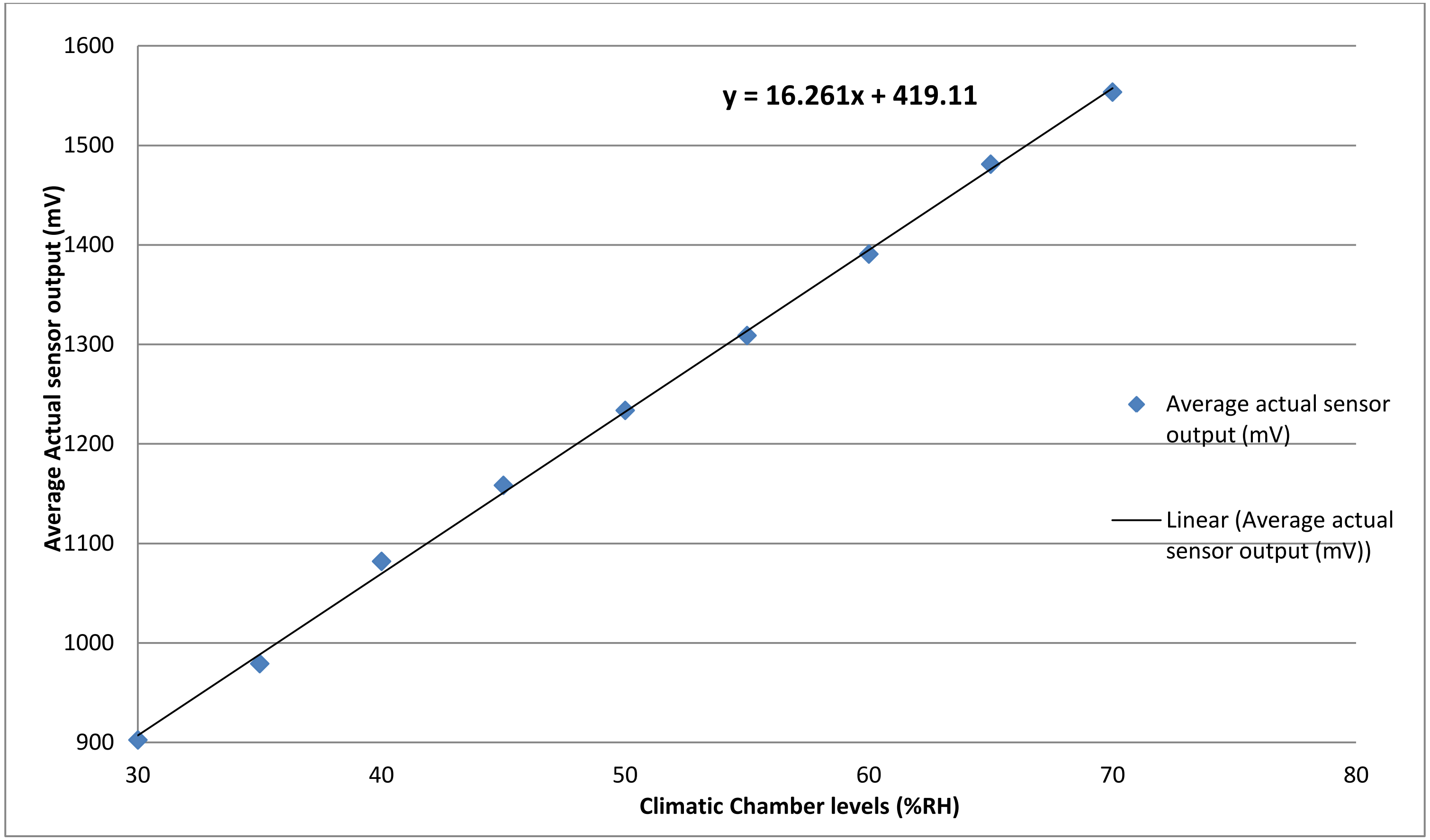
As an example the information on Table 3.12 show the actual sensor output signal from figure 3.10, amended and converted into the appropriate relative humidity equivalents. The data for the actual sensor outputs was taken from appendix 2d. The amended and converted humidity values of the actual sensor outputs are quite close to the climatic chamber setting. This method will be used to convert the actual sensor outputs for future experiments.

Table 3.12: Amended and converted actual sensor outputs

Climatic Chamber levels (%RH)	**Expected sensor output (mV)****	**Actual Voltage output (V_{out})**	**Converted V_{out} to %RH**	**Errors between the Climatic Chamber levels and the converted V_{out}**
30	907	902.38	29.72	0.28
35	1059	979.08	34.44	0.56
40	1210	1081.90	40.76	0.76
45	1361	1158.29	45.46	0.46
50	1512	1233.61	50.09	0.09
55	1663	1308.86	54.72	0.28
60	1815	1390.65	59.75	0.25
65	1966	1481.02	65.30	0.30
70	2117	1553.45	69.76	0.24 **(Average error: 0.4; S.D: 0.2)**

Key: **This is what the sensor outputs should be if the climatic chamber output was converted to sensor voltage (mV)

Figure 3.10: Linear regression model generation for the method of least squares



Key: The six sensors that measured in the calibration chamber at 25 °C (R = 0.9974) was used in the figure above to find out the linear regression equation. The output voltages from the six sensors were averaged and epoch points were compared to the climatic chamber levels.

3.2.5 Calibration of the temperature sensors

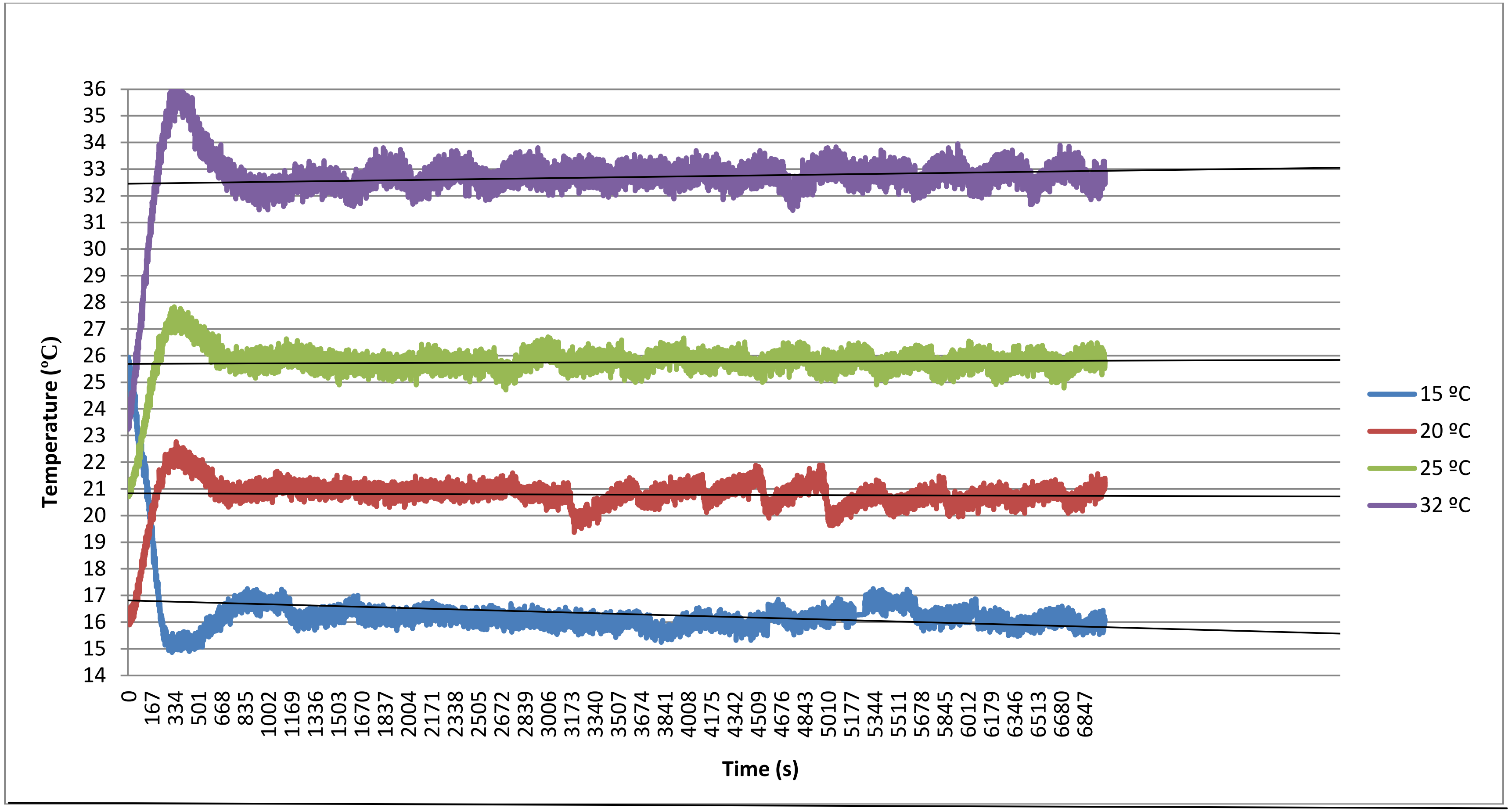
When the humidity sensors were calibrated, the temperature sensors also measured in the climatic chamber because they were connected to the humidity measurement system. However they were not analysed like the humidity sensors were. This is because humidity was the main variable in the assessment of sitting profiles in chapter 4. Therefore calibrating the humidity sensors were imperative to determining their characteristics and measurement limits. However to demonstrate that the temperature sensors were working accurately, their output signals were analysed when they measured alongside the humidity profiles to the four temperatures (15 ^{o}C, 20 ^{o}C, 25 ^{o}C and 32 ^{o}C) in the climatic chamber. Six temperature sensors measured each temperature setting in the climatic chamber and they were averaged. For the four temperatures, four average signals were calculated and they are displayed on Figure 3.11 across a time of 1 hour and 54 minutes. The duration of this test was synchronous to the humidity calibration experiment above. Table 3.13 displays the arithmetic means for the all four temperatures. The sensors measured the four varieties of temperatures accurately with low standard deviations.

Table 3.13: Arithmetic means for the four temperatures of a period of 1 hour and 54 minutes.

	15 ºC	20 ºC	25 ºC	32 ºC
Mean	16.2	20.8	25.8	32.7
S.D	0.3	0.3	0.3	0.4
Min	15	19	25	31
Max	17	22	27	34

Key: Arithmetic means for the all four temperatures. The sensors measured the four varieties of temperatures accurately with low standard deviations.

Figure 3.11: Temperature sensors in the climatic chamber



Key: Each line on the graphs above represents the average of six sensors measuring at four different temperatures set by the climatic chamber

Table 3.14. Regression analysis calculations for LMS.

Y:Average Actual sensor output (mV)	X: Expected Sensor output (mV)		E(x,y)	E(x)	E(y)	E(x^2)	E(y^2)
902.3809524	30		27071.42857	450	11089.25	900	814291.3832
979.0833333	35		34267.91667			1225	958604.1736
1081.904762	40		43276.19048			1600	1170517.914
1158.285714	45		52122.85714			2025	1341625.796
1233.607143	50		61680.35714			2500	1521786.583
1308.857143	55		71987.14286			3025	1713107.02
1390.654762	60		83439.28571			3600	1933920.667
1481.02381	65		96266.54762			4225	2193431.524
1553.452381	70		108741.6667			4900	2413214.3
		total (A)	578853.3929		Total (C)	24000	14060499.36
				E(x) *E(Y)			
				4990162.5			
				div by 9		E(x)^2)	
			(B)	554462.5		202500	
						divide by 9	
					(D)	22500	
		(A) - (B)	24390.89286				
		(C) - (D)	1500		b0		
		b1	=		bi* Ex	7317.267858	
		(A) - (B) / (C) - (D)	16.26059524		Ey-(bi*Ex)	3771.982142	
			(slope of linear model)		Divide by 9	419.1091269	(y-intercept)

3.3 Study 1: Comparing the performance of existing and new sensors

3.3.1 Study outline

The measuring performance of a set of six existing humidity sensors (HIH4000-003) and six brand new humidity sensors (HIH4000-004) were compared through calibration in a climatic chamber (FS990 – 40 V, Design Environmental Ltd, Ebbw Vale; UK). This was done to investigate if existing sensors reduce in performance over time (Lohbeck, 2008; Chen and Lu, 2005; Cavlier, 2012). The existing humidity sensors were purchased in 2008 for experimental investigation and data was published in previous studies (McCarthy et al., 2009; Cascioli et al., 2010). The brand new sensors were purchased in 2010 for the purpose of the authors study. For calibration the existing and new sensors sets were placed in the chamber separately but they were exposed to the same humidity profile: ascending and descending humidity levels between 30 %RH and 70 %RH with 5 %RH incremental steps. The sensors were left to measure at each step for 10 minutes. Simultaneous to the humidity profile, the climatic chamber was set to a temperature of 20 ^{o}C. Please refer to Table 3.5 for the aims, objectives, research question and analysis.

3.3.2 Results

The six sensors in each set were averaged to form one mean value. On both mean profiles, at each 5 %RH incremental level on the humidity profile 20 epoch points were selected and analysed. The arithmetical means are shown on Table 3.15. The existing sensors consistently measured lower than the new sensors except when the climatic chamber is set between 50 %RH and 70 %RH humidity on both ascending and descending levels (Figure 3.12). The existing sensors peak to 90%RH. The new sensors appear to measure very close to the profile of the climatic chamber (figure 3.12). On the ascending part of the profile, the new sensors measure almost the same as the climatic chamber (between 30 %RH and 45 %RH), however for the rest of it and all of the descending part of the profile, they consistently measures less. The average error (Table 3.15) between the chamber and the existing sensors is 9.45 ± 5.2 %RH (range: 0.9 %RH to 20.2 %RH) which is the larger than the average error between the chamber and the new sensors 2.16 ± 1.3 %RH (range: 0.12 %RH to 4.21 %RH). The error between the existing sensors and the new sensors are large as well, 10.54 ± 6.1 %RH (range: 2.44 %RH to 24.4 %RH). The complete errors at every incremental level across the humidity profile can be seen on Figure 3.13. This figure confirms that the existing sensors have higher errors from their irregular dips and peaks. The new sensors have minimal errors when compared to the climatic chamber.

The parametric analysis (independent samples t-test) compared the mean humidity outputs of the existing and new sensors and revealed a significant difference between both groups at the 5% confidence level over the entire humidity profile ($p < 0.05$; two-tailed). The magnitude of differences in both the means scores can be seen on Table 3.16 under the title 'mean diff' and the corresponding 95 % confidence interval (CI) of the difference (lower and upper) is under '95 % CI'. The effect size for existing and new sensors is also given. The 'effect size' indicates the magnitude of differences between the existing and new sensors and is described as the eta squared (eta^2) and Cohen's D. For both the sensors the eta^2 (incorporates the t-test score), was 0.999· which is considered to be a large effect.

Table 3.15: Arithmetical statistics of both the existing (six sensors) and new (six sensors) humidity sensors.

	Existing (%RH)				New (%RH)				Errors (%RH)		
Chamber	Mean	s.d	min	max	Mean	s.d	min	max	Chamber Vs. Existing	Chamber Vs. New	Existing - New
30	16.41	0.30	15.86	16.94	29.88	0.10	29.69	30.05	13.59	0.12	13.47
35	22.05	0.15	21.80	22.30	34.58	0.17	34.18	34.80	12.95	0.42	12.53
40	31.21	0.31	30.36	31.54	39.23	0.10	38.97	39.39	8.79	0.77	8.02
45	41.69	0.17	41.39	41.98	44.13	0.13	43.87	44.43	3.31	0.87	2.44
50	50.90	0.19	50.61	51.20	48.05	0.13	47.86	48.31	0.90	1.95	2.85
55	60.19	0.17	59.89	60.58	53.31	0.11	53.11	53.56	5.19	1.69	6.88
60	69.58	0.28	68.98	70.03	57.04	0.24	56.77	57.59	9.58	2.96	12.54
65	79.81	0.21	79.32	80.22	61.12	0.35	60.39	61.70	14.81	3.88	18.69
70	90.17	0.18	89.85	90.50	65.79	0.46	65.16	66.63	20.17	4.21	24.38
65	79.38	0.26	78.93	79.89	61.64	0.24	61.14	62.13	14.38	3.36	17.74
60	70.91	0.22	70.55	71.28	55.91	1.07	54.54	58.25	10.91	4.09	14.99
55	60.35	0.18	60.04	60.72	52.03	0.12	51.79	52.23	5.35	2.97	8.33
50	51.53	0.79	50.43	53.25	47.50	0.19	46.96	47.78	1.53	2.50	4.04
45	39.16	0.17	38.90	39.39	43.14	0.08	42.98	43.28	5.84	1.86	3.97
40	29.99	0.16	29.66	30.23	38.51	0.14	38.20	38.71	10.01	1.49	8.52
35	21.75	0.15	21.49	22.01	32.78	0.18	32.56	33.20	13.25	2.22	11.04
30	19.88	0.17	19.59	20.11	28.67	0.12	28.46	28.87	10.12	1.33	8.78
							Average errors:		9.45 ± 5.2	2.16 ± 1.3	10.54 ± 6.1

Figure 3.12: Calibration results of sensors plotted using the epoch points

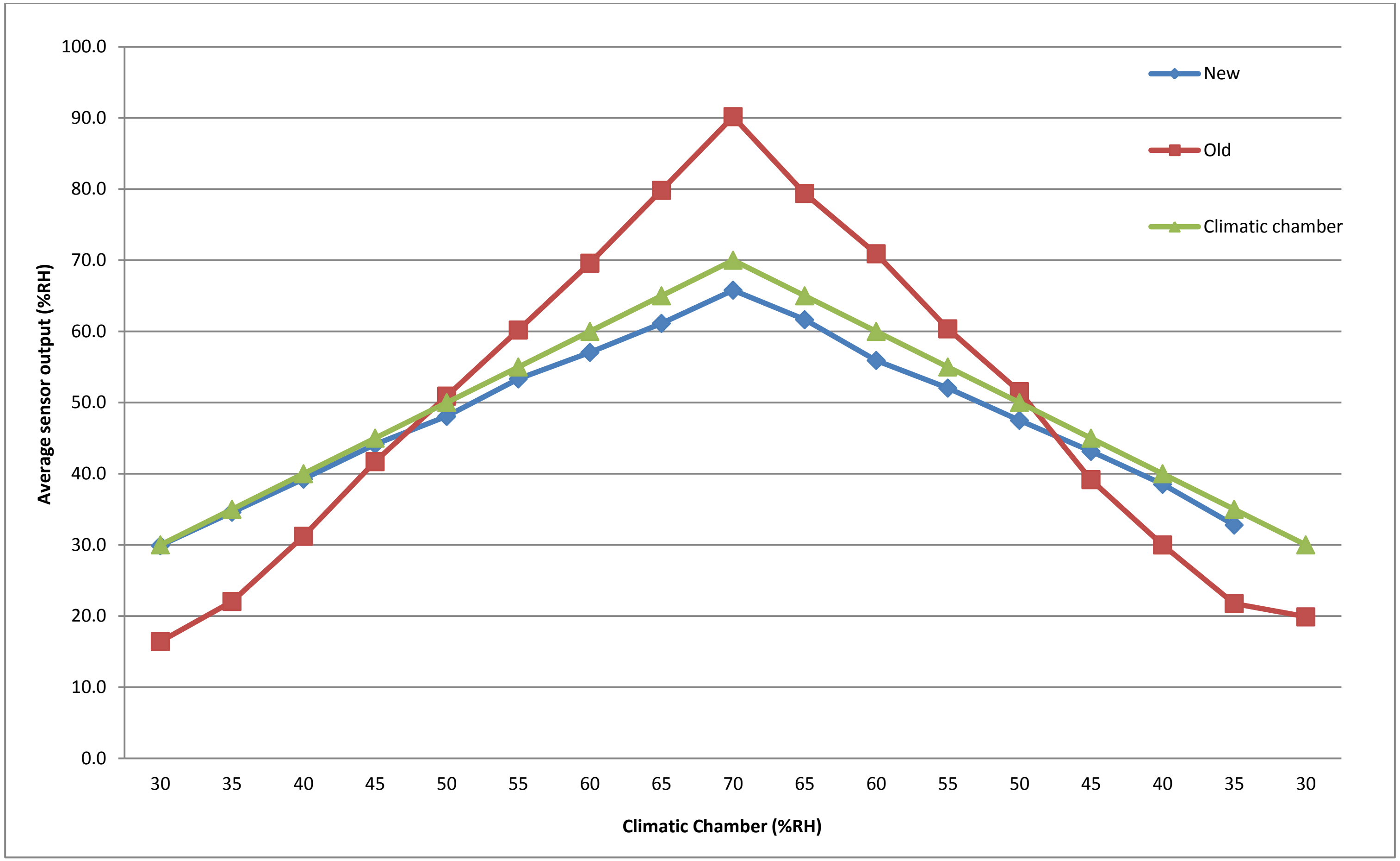


Figure 3.13: Errors between the climatic chamber and both the sensors

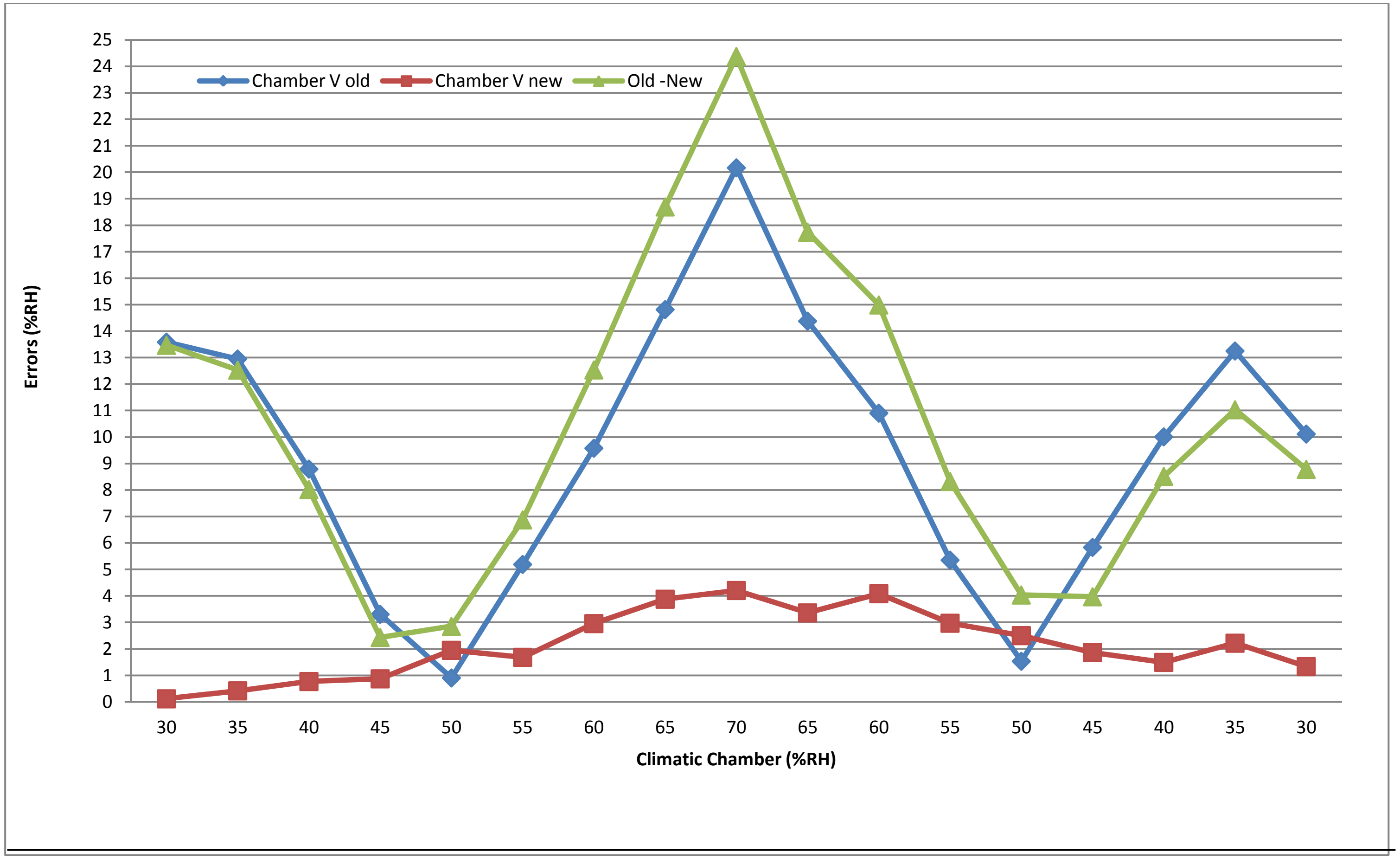


Table 3.16: Independent samples t-test to compare the means scores of two different groups of people.

Climatic Chamber	EXISTING Mean	s.d.	NEW Mean	s.d.	Inferential statistical results: Levene's Test sig (p<0.05) indicating a sig. difference.	t-test	st error diff	Mean difference (new-existing)	Effect size	95% CI
30	16.41	0.30	29.88	0.10	0.000	-187.8	0.72	-13.5	0.9989	-13.6 to -13.3
35	22.06	0.15	34.59	0.17	0.000	-242	0.01	-12.5	0.9994	-12.6 to -12.4
40	31.19	0.31	39.22	0.10	0.000	-110.7	0.07	-8.0	0.9969	-8.2 to 7.8
45	41.68	0.16	44.12	0.13	0.000	-52.1	0.04	-2.4	0.9862	-2.5 to -2.4
50	50.92	0.19	48.04	0.12	0.000	57.3	0.05	2.9	0.9886	2.8 to 2.9
55	60.12	0.16	53.32	0.10	0.000	158.5	0.04	6.9	0.9985	6.7 to 6.9
60	69.58	0.28	57.04	0.24	0.000	149.7	0.08	12.5	0.9983	12.4 to 12.7
65	79.83	0.21	61.15	0.34	0.000	209.2	0.09	18.7	0.9991	18.5 to 18.9
70	90.19	0.17	65.75	0.43	0.000	237.59	0.10	24.4	0.9993	24.2 to 24.6
65	79.35	0.24	61.66	0.22	0.000	245.2	0.07	17.7	0.9994	17.5 to 17.8
60	70.92	0.22	55.95	1.05	0.000	62.4	0.24	14.9	0.9903	14.5 to 15.5
55	60.36	0.19	52.03	0.12	0.000	169.1	0.05	8.3	0.9987	8.2 to 8.4
50	51.59	0.76	47.5	0.19	0.000	23.2	0.18	4.1	0.9341	3.7 to 4.4
45	39.17	0.16	43.13	0.08	0.000	-95.74	0.04	-3.9	0.9959	-4.0 to -3.9
40	30.01	0.15	38.5	0.14	0.000	-180.5	0.05	-8.5	0.9988	-8.6 to -8.4
35	21.76	0.14	32.79	0.18	0.000	-215.5	0.05	-11.0	0.9992	-11.1 to -10.9
30	19.89	0.16	28.68	0.12	0.000	-194.7	0.05	-8.8	0.9990	-8.9 to -8.7

3.4 Study 2: Sensor verification experiment after exposure to desiccant

3.4.1 Study outline

This study focused on a technique to remove moisture from six humidity sensors (HIH4000-004) in a sealed environment. These sensors had some usage from the sitting study (chapter 4) and therefore it was envisaged that exposure to moisture may change its measuring characteristics. This was determined when the same set of sensors were compared to an existing set of sensors ($p < 0.05$) with reported usage (McCarthy et al., 2009; Cascioli et al., 2010). This technique was previously used in a comparative calibration study where humidity sensors (HIH4000-003) were required to measure three conditions the ambient room relative humidity (54.8 % ± 0.6 %RH), dew point (97.8 ± 0.3 %RH), and desiccant point (3.1 ± 0.2 %RH) (McCarthy et al., 2009). The HIH4000-004 sensors were dried in the same desiccant experimental conditions as the McCarthy et al., (2009) study. The sensors will be required to measure the ambient room humidity in addition to the ascending and descending relative humidity profile in the climatic chamber between 30 %RH and 70 %RH with 5 %RH increments. This will be done before and after drying and the average of the six sensors will be used for analysis. Table 3.5 contains the design for this study.

3.4.1 i Desiccant process

One hundred grams of anhydrous calcium chloride (desiccant) was placed inside a jar containing six humidity sensors (HIH4000-004) with a secure lid (Figure 3.14). Calcium chloride is a desiccant, meaning that it will continue to absorb moisture until it forms a solution with a vapour pressure in equilibrium with atmospheric humidity. In the sealed jar it will effectively dry out any moisture thus reducing the internal humidity. The same calcium chloride granules were used in the McCarthy et al study (2009) and therefore it required recalibrating to ensure its drying capabilities were still effective. For recalibration, the calcium chloride granules were placed in a porcelain bowl where they were heated to 200 °C for two hours in a vacuum oven with 900 mbar of vacuum. After two hours the heating was turned off and the calcium chloride was allowed to cool overnight in the vacuum environment. This method was advised and carried out by the team at the University of South Wales, Centre for Automotive and Power System Engineering (CAPSE). The rim of the jar where the sensor wires rested was covered in a thin layer of aluminium foil and then topped over with Vaseline petroleum jelly to create an airtight seal (Figure 3.14b) (McCarthy et al., 2009). The sensors were generally investigated in two ways: firstly they measured the room and sealed environment and then secondly they were calibrated in a climatic chamber.

3.4.1ii Measuring the sealed and ambient environments

Before sealing the sensors in the jar they measured the environment for 30 minutes. After sealing and drying (48 hours) the sensors measured the dry environment for 30 minutes. After step 2 the lid was removed and the sensors measured the environment for 30 minutes. Each humidity sensor outputs one measure per second (1 kHz) therefore producing 1800 measurements for 30 minutes. The outputs of all six sensors were average and analysed. Due to this volume of data twenty stable epoch points were chosen on the average (mean) data of the sensors at these specific times: start, 1, 5, 10, 20, 30 minutes. The arithmetical means for this are displayed in Table 3.17 and displayed on Figure 3.15. For reference the room humidity was measured using a multi-meter (average: 42.1 ± 0.3 %RH.

3.4.1iii Calibration of sensors before and after drying

The second test involved the same six sensors calibrated in the climatic chamber before and then after they were dried. The sensors measured the following humidity profile: ascending and descending levels of 30 %RH to 70 %RH with 5 %RH increments. At each incremental humidity level, twenty stable epoch points were chosen and the arithmetical means were computed (Appendix 2d). In addition to this the sensors in either situation (before and after) were in turn compared (errors) to the humidity profile of the climatic chamber (Figure 3.16 and Table 3.18).

3.4.2 Results

3.4.2i Test one: Measuring sealed and ambient environments.

Before drying, the sensors measured less (average: 39.62 ± 0.3 %RH: range: 38.8 to 40.2 %RH) than the room humidity (42.1 %RH). After the sensors dried for 48 hours they measured the dry sealed environment and the measurements were very low (average: 22.9 ± 0.3 %RH: range: 22.02 to 24.42; room humidity: 41.8 %RH). When the lid was removed and the sensors were exposed to the room environment they measured higher (average: 48.08 ± 1.1 %RH: range: 45.20 to 50.48 %RH; room humidity: 42.3 %RH) than before it was dried. Figure 3.15 was derived from table 3.17 also contains the average room humidity (42.1 ± 0.3 %RH). Drying out the sensors may have improved the accuracy and sensitivity of the sensors however this can only be verified in the next experiment when sensors are measured against a traceable source (climatic chamber).

3.4.2ii Test two: Calibration of sensors before and after drying.

When compared to the climatic chamber (Figure 3.16) the dried sensors consistently measured higher humidity (than sensors before dried) at the descending part of the profile between 65 %RH and 30 %RH (errors between 1.6 %RH and 4.6 %RH). However on the ascending part of the profile, the dried sensors measured higher (than the sensors before drying) on all incremental levels except at 55 %RH, 65 %RH and 70 %RH (errors before and after between 1 %RH and 1.6 %RH) (Table 3.18). When sensors were compared before and after drying throughout the humidity profile, the errors found were 2.8 ± 1.7 %RH (range 1 to 8 %RH) (Table 3.19). The parametric analysis on Table 3.19 (paired sampled t-test) statistically compared the sensors before and after drying in the climatic chamber at each humidity level. Each set of data was tested for normality before commencing with the comparison. Using the Shapiro-wilks test ($p > 0.05$) the null hypothesis (normality) was accepted. Sensors revealed no significant difference before and after drying at 50 %RH and 65 %RH on the ascending part of the profile ($p > 0.05$; two –tailed). At all other levels, the difference between before and after drying revealed a significant difference between groups at the 5% level of confidence ($p < 0.05$; two-tailed). The mean errors on were between 0.95 %RH and 8 %RH. The larger errors were found at the lower humidity levels. The eta squared values reports the magnitude of difference which was large across the humidity profile and moderate at 50 %RH on the ascending level.

3.4.2iii Comparing sensors to the climatic chamber:

The differences between the humidity profile set by the climatic chamber and the sensors before and after drying are on Figure 3.17. On figure 3.17 the '0' value on the x-axis represents the climatic chamber's humidity profile. The positive and negative scale on the y-axis represents how far the sensors are measuring from the climatic chamber's humidity profile. Before drying the sensors measured less than the climatic chamber (indicated by the negative sign as being lower than the chamber setting): -1.68 ± 2; range: -4.17 to 3.14. After drying the sensors measured below and above than the chamber settings: 0.61 ± 3.71 %RH, range -5.61 to 7.56 %RH. On Figure 3.17 for conditions (before and after drying) there were minimal errors between 40 %RH to 70 %RH and back down to 40 %RH (between the ascending and descending scale). There were however more errors found before drying (-2.24 ± 1.6; range: -4.17 to 1.63) than after drying (-1.34 ± 2.18; range -5.16 to 2.06) (45%RH at descending was not considered).

Figure 3.14: Set up of sensors in a jar with exposure to the dessiccant

a. Sensors in jar **b. Seal on rim** **c. Lid on jar**

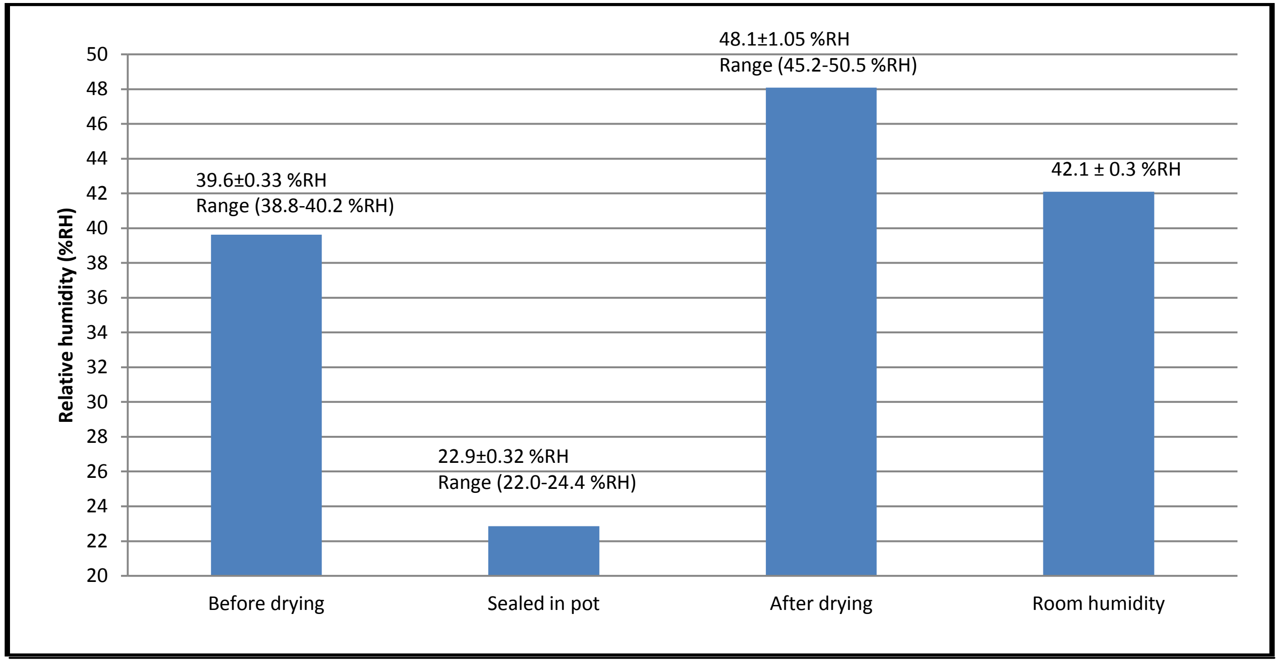
Key: The three picture show how the humidity sensors being exposed to a drying agent. The desiccant was placed at the bottom of the jar and a Vaseline seal was created to ensure minimal escape of air.

Table 3.17: The average of six humidity sensors (HIH4000-004) measuring in three conditions.

Three conditions	Arithmetical statistics according to the timeline (%RH)						
a) Open air before drying	**Start**	**1**	**5**	**10**	**20**	**30**	**Average**
Mean	39.88	40.08	39.98	39.84	39.41	38.96	39.62
s.d	0.0764	0.0468	0.0757	0.0519	0.0537	0.0145	0.3269
min	39.65	39.97	39.84	39.74	39.33	38.95	38.81
max	39.99	40.14	40.11	39.93	39.50	38.97	40.20
b) Sensors still sealed in jar after 48 hours	**Start**	**1**	**5**	**10**	**20**	**30**	**Average**
Mean	23.08	23.19	23.14	23.026	22.86	22.64	22.85
s.d	0.2426	0.1394	0.1029	0.0993	0.1093	0.1039	0.3196
min	22.37	22.89	22.94	22.81	22.68	22.4	22.02
max	23.42	23.45	23.33	23.19	23.07	22.85	24.42
c) Open air after drying	**Start**	**1**	**5**	**10**	**20**	**30**	**Average**
Mean	45.85	46.49	47.18	47.31	48.54	50.16	48.08
s.d	0.3597	0.2687	0.6081	0.8887	0.1695	0.4493	1.0549
min	45.20	45.96	45.74	46.29	48.25	49.85	45.20
max	46.66	47.03	47.92	48.69	48.80	50.48	50.48
Room humidity (multimeter) : a) 42.1 %RH b) 41.8 %RH c) 42.3 %RH (average: 42.1 ± 0.3 %Rh)							

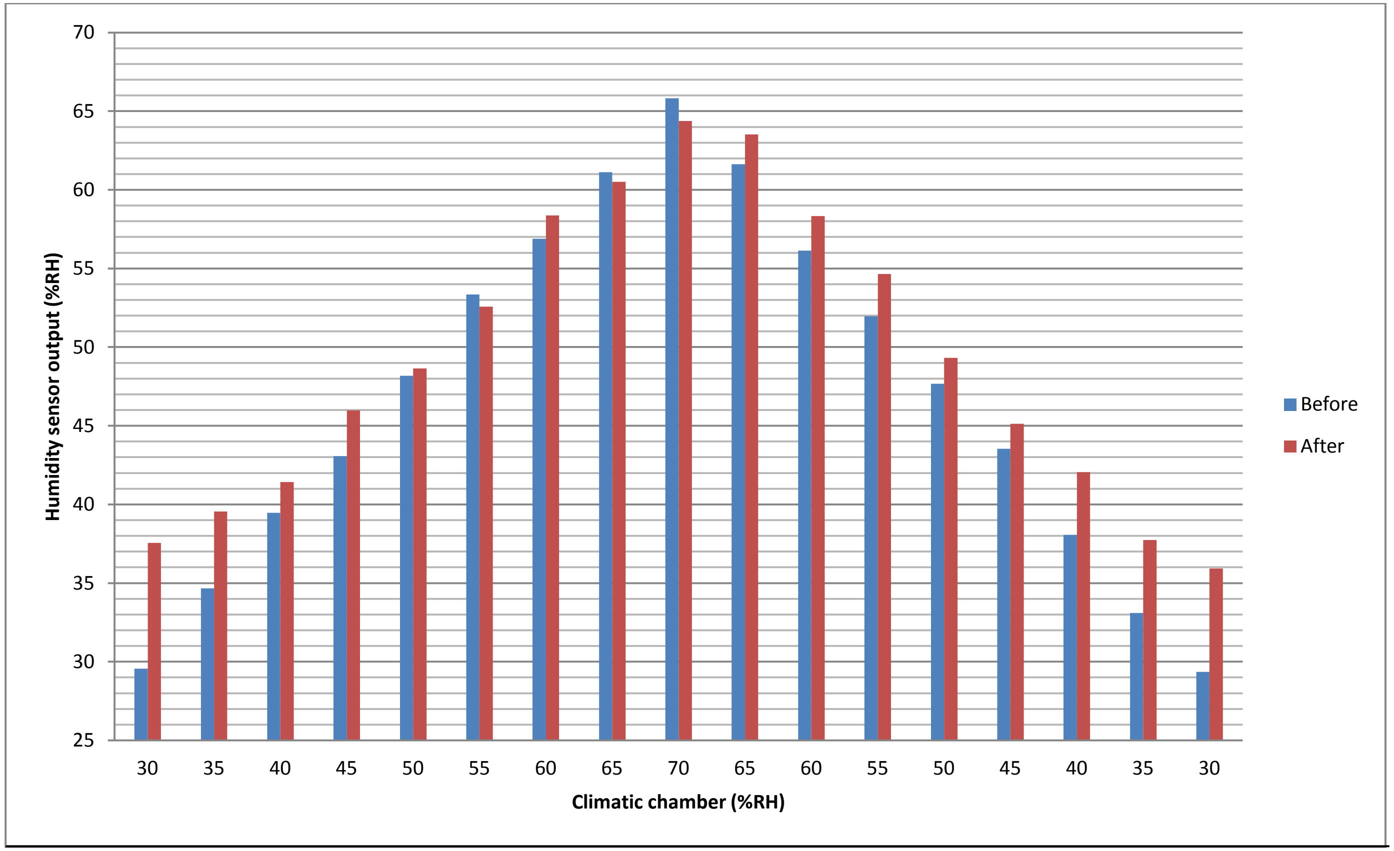
Key: The average of six humidity sensors at each Epoch point. 20 points were averaged across the time line. S.d. refers to 1 standard deviation..

Figure 3.15: Average of humidity sensors (HIH4000-004) measuring across the complete 30 minutes.



Key: Difference between the sensors in three conditions before dried, after dried and when sealed in the pot. The room humidity was added for reference

Figure 3.16.: Relative humidity before and after drying when compared to traceable standards.



Key: Comparison of sensors before and after drying to see the impact of drying on their measurement abilities.

Table 3.18: Errors of sensors before and after drying compared to the climatic chamber

	30		35		40		45		50		55		60		65		70	
	B*	A*	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A
Mean	-0.44	7.56	-0.32	4.56	-0.54	1.41	-1.92	5.66	-1.82	-1.35	-1.65	-2.43	-3.12	-1.63	-3.87	-4.50	-4.17	-5.61
s.d	0.16	1.07	0.16	1.18	0.10	1.91	0.29	1.37	0.09	1.89	0.23	0.80	0.19	1.28	0.12	1.65	0.18	1.09
min	-0.88	5.75	-0.82	1.89	-0.92	-1.71	-2.49	3.06	-2.02	-5.27	-2.38	-3.94	-3.42	-4.08	-4.16	-6.75	-4.59	-7.54
max	0.16	9.66	-0.13	6.44	-0.42	4.31	-1.45	7.92	-1.64	1.88	-1.31	-0.90	-2.73	0.64	-3.64	-0.78	-3.78	-3.34
	65		60		55		50		45		40		35		30		E(B)*	E(A)*
	B	A	B	A	B	A	B	A	B	A	B	A	B	A	B	A		
Mean	-3.36	-1.49	-3.87	-1.68	-3.03	-0.36	1.63	-0.67	-1.46	0.13	-1.93	2.06	-1.90	2.74	3.24	5.93	-1.68	0.61
s.d	0.24	1.32	0.43	1.38	0.17	0.90	0.15	0.79	0.16	0.74	0.22	0.91	0.11	1.02	0.20	1.29	1.98	3.71
min	-3.86	-4.10	-4.84	-4.25	-3.44	-2.03	1.32	-2.13	-1.88	-1.31	-2.65	-0.28	-2.13	0.74	2.65	3.02	-4.17	-5.61
max	-2.87	0.50	-3.27	0.26	-2.70	2.01	1.82	0.92	-1.23	1.26	-1.57	4.02	-1.71	5.03	3.47	7.89	3.24	7.56

Key: B* = Before drying; A* = After drying; E(B)* = Error Before drying, E(A)* = Error After drying.

s.d. refers to 1 standard deviation.

Figure 3.17: Errors of sensors before and after drying compared to the climatic chamber.

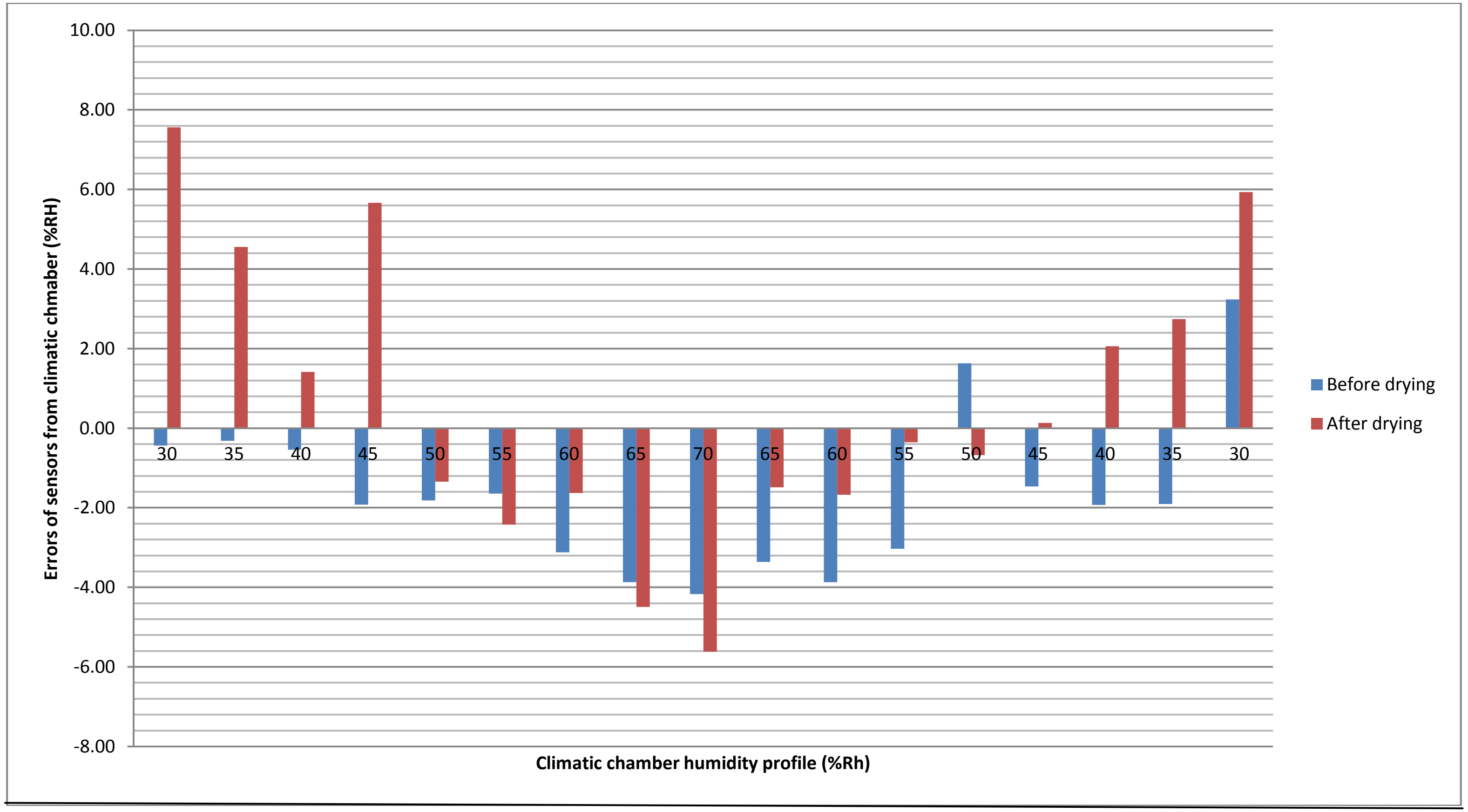


Table 3.19: Parametric results for the paired samples t-test

No	Samples	Mean	s.d	Min/Max	Mean error	s.d	Min/Max	t-test	p-value	result	Eta^2	Effect
1	bef30	29.56	0.16	29.12/29.76	8	1.11	6.09	-33.17	0.000	Difference	0.98	Large
	aft30	37.56	1.07	35.75/39.66			9.99					
2	bef35	34.68	0.16	34.18/34.87	4.87	1.15	2.02	-19.473	0.000	Difference	0.95	Large
	aft35	39.56	1.18	36.87/41.44			6.74					
3	bef40	39.46	0.1	39.09/39.58	2.29	1.51	0.08	-4.59	0.0002	Difference	0.51	Large
	aft40	41.41	1.91	38.29/44.31			5.22					
4	bef45	43.08	0.29	42.51/43.56	2.6	1.36	0.18	-8.47	0.000	Difference	0.78	Large
	aft45	45.66	1.37	43.06/47.92			5.14					
5	bef50	48.18	0.09	47.99/48.36	1.69	0.94	0.38	-1.128	0.273	No difference	0.06	Moderate
	aft50	48.65	1.89	44.73/51.88			3.84					
6	bef55	53.35	0.23	52.62/53.69	0.95	0.67	0.05	4.073	0.001	Difference	0.45	Large
	aft55	52.57	0.8	51.06/54.1			2.27					
7	bef60	56.88	0.19	56.58/57.26	1.72	1.02	0.16	-5.09	0.00006	Difference	0.56	Large
	aft60	58.37	1.28	55.9/60.64			4.06					
8	bef65	61.13	0.12	60.84/61.36	1.56	0.78	0.37	1.723	0.1	No difference	0.13	Large
	aft65	60.5	1.65	58.25/64.22			3					
9	bef70	65.83	0.18	65.41/66.22	1.58	0.89	0.082	5.962	0.000	Difference	0.64	Large
	aft70	64.39	1.09	62.46/66.66			3.4					
10	dwnbef65	61.64	0.24	61.42/62.13	1.96	1.08	0.37	-7.04	0.000	Difference	0.71	Large
	dwnaft65	63.51	1.32	60.89/65.49			3.74					
11	dwnbef60	56.13	0.43	55.16/56.73	2.27	1.28	0.25	-7.126	0.000	Difference	0.72	Large
	dwnaft60	58.32	1.38	55.75/60.26			4.74					
12	dwnbef55	51.97	0.17	51.56/52.29	2.67	0.97	0.94	-12.673	0.000	Difference	0.89	Large
	dwnaft55	54.64	0.9	52.97/57.01			5.14					
13	dwnbef50	51.63	0.15	51.32/51.83	2.31	0.85	0.71	12.375	0.000	Difference	0.88	Large
	dwnaft50	49.33	0.79	47.87/50.92			3.91					
14	dwnbef45	43.54	0.16	43.12/43.77	1.59	0.78	0.02	-9.372	0.000	Difference	0.81	Large
	dwnaft45	45.13	0.74	43.69/46.26			2.59					
15	dwnbef40	38.07	0.22	37.35/38.43	3.99	0.84	1.78	-21.642	0.000	Difference	0.96	Large
	dwnaft40	42.06	0.91	39.72/44.03			5.82					
16	dwnbef35	33.1	0.11	32.87/33.29	4.65	1.01	2.75	-21.16	0.000	Difference	0.96	Large
	dwnaft35	37.74	1.02	35.74/40.03			6.76					
17	dwnbef30	33.24	0.2	32.65/33.47	2.74	1.2	0.41	-9.574	0.000	Difference	0.82	Large
	dwnaft30	35.93	1.29	33.02/37.89			4.51					
Average of all mean errors± 1 standard deviation (s.d.): 2.79 ± 1.73 %RH; range 0.95 to 8 %RH							**Average of mean errors between 40% to 70 %RH and back to 40 %RH : 2.09 ± 0.75 %RH; range 0.95 to 3.99 %RH**					

3.5 Study 3: Endurance of humidity sensor with respect to time and location

3.5.1 Study outline

Five new humidity sensors (Honeywell HIH 4000-004) and five new temperature sensors (LM35) were paired and placed in 5 different controlled indoor environments (Table 3.20). These sensors have not been used in any other experiments. These studies were carried out in the University of South Wales. Four paired sensors were powered with a 6 V cell supply in a housed set up and one pair that was unpowered. These paired components were placed in their respective locations for 7 months (month 0 to 6). All humidity sensors were sampled once every month for six months in a climatic chamber. Every month the humidity sensors would be manually removed from their housing and soldered onto one generic connection board. The calibration involved observing the sensors ability to accurately follow an ascending and descending humidity profile between 30 %RH and 70 %RH with 5 %RH incremental steps (10 minutes at each step). The climatic chamber was set to a temperature of 25 °C. After calibration the sensors were connected back in their original battery powered housing at their respective locations. Table 3.5 contains the design for this study. Appendix 2e displays the dates and average room humidity's recorded.

3.5.2 Results

In test one, sensors from each location were individually measured once per month across seven months. Table 3.21 shows the statistical results found after applying the one-way repeated measures ANOVA test on SPSS (version 20) to each individual location.

Drawer: The p-value (0.225) is greater than 0.05 ($p > 0.05$) therefore it may be concluded that there is no statistically significant effect for time. This suggests that there was no change in confidence scores across the seven different time periods. Although there was no difference found the effect size was large (0.842). Using the commonly used guidelines proposed by Cohen (1988) this result was a large effect.

Wall: The p-value (0.10) is greater than 0.05 ($p > 0.05$), therefore it may be concluded that there is no statistically significant effect for time. This suggests that there was no change in confidence scores across the seven different time periods. Although there was no difference, the effect size was large (0.84).

Seat: The p-value (0.003) is less than 0.05 ($p < 0.05$), therefore it may be concluded that there is a statistically significant effect for time. This suggests that there was a change in confidence scores across the seven different time periods. Due to the statistically significant differences found between the seven months, there is a need to assess the effect size of this result. To do this the partial eta squared was found to be 0.992. According to Cohen (1988), this result indicates a very large effect size. Obtaining a statistically significant effect suggests that there is a difference somewhere among the groups. It does not state which group or month differs from one another. This information is provided in the pair-wise comparison, where it compares each pair of the months and indicates whether a difference between them is significant. The value of less than 0.05 indicates a significant difference. Differences ($p< 0.05$; 95 % CI) were found between month 1 and 2 ($p = 0.015$) and months 1 and 5 ($p = 0.001$).

Kitchen: The p-value (0.021) is less than 0.05 ($p < 0.05$), therefore it can be concluded that there is a statistically significant effect for time. This suggests that there was a change in confidence scores across the seven months. The effect sizes between the differences were investigated and the partial eta squared was found to be large (0.971). The pairwise comparison indicated where the differences lie and gave the following results ($p < 0.05$):

Month 0 and 3 (0.005)	Month 0 and 4 (0.001)	Month 0 and 5 (0.000)
Month 0 and 6 (0.002)	Month 1 and 3 (0.017)	Month 1 and 4 (0.000)
Month 1 and 5 (0.010)	Month 1 and 6 (0.028)	Month 2 and 4 (0.018)
Month 3 and 6 (0.029)		

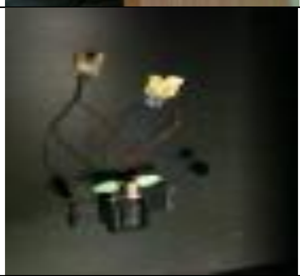
Table: The p-value (0.0003) is less than 0.05 ($p < 0.05$), therefore it may be concluded that there is a statistically significant effect for time. This suggests that there was a change in confidence scores across the seven months. This change may be indicated by the partial eta squared which was found to be 0.998 indicating a large effect. The differences may be found using the pairwise comparison results as follows ($p < 0.05$; 95 % CI; Cohen).

Month 0 and 6 (0.004)	Month 2 and 4 (0.009)
Month 1 and 3 (0.021)	Month 2 and 5 (0.006)
Month 1 and 6 (0.005)	Month 2 and 6 (0.002)

In test two, the sensors across locations were simultaneously compared to one another at each individual month (between months zero to seven). Table 3.23 shows the statistical results found after applying the one-way between-groups ANOVA test on SPSS (version 20). A one-way between-groups analysis of variance was conducted to explore the impact of humidity on location of sensors (Table 3.23). Levene's test of significance indicates whether the data is reliable for analysis and in this study it was ($p > 0.05$). The sensors were monitored for seven months and the ANOVA analysis compared the five locations at each month. Between the set of locations at all months there was no statistically significant difference found ($p > 0.05$) (Table 3.22). The significant F score indicated whether the null hypothesis can be rejected.

A large F ratio indicates that there is more variability between the months than there is between groups. The F-score is a ratio between the months and within the months. If the null hypothesis is true then these are both estimates of the same thing and the ratio will be around 1. In this case all the F-scores do not reach 1. Therefore the null hypothesis can be rejected (reject the fact that there is a difference between locations). To double check the differences, the post hoc tests were checked. The Tukey significance was found across all data ($p > 0.05$) confirming no significant difference.

Table 3.20: Humidity sensors in five different locations

Placement	Diagram
Sensors in a dark drawer.	
Sensors embedded in a foam seat with a cover.	
Sensors on the shelf.	
Sensors on a table	
Sensors on kitchen cabinet	

Key: Actual picture taken by author of the five different sensor locations

Table 3.21: Results from the one-way repeated measures ANOVA test

Month	Drawer								
	0	1	2	3	4	5	6	Wilks Lambda, probability value.	Partial Eta²
Mean	50.5	51.9	47.3	53.3	51.1	50.8	50.6	0.225	0.842
s.d	13.6	13.1	13.1	13.8	12.7	12.9	13.3		
Month	Wall								
	0	1	2	3	4	5	6	Wilks Lambda, probability value.	Partial Eta²
Mean	50.4	44.6	48.6	54.5	51.8	52.3	51.1		0.84
s.d	13.8	17.4	12.8	12.3	12.9	12.4	12.7	0.10	
Month	Seat								
	0	1	2	3	4	5	6	Wilks Lambda, probability value.	Partial Eta²
Mean	50.4	51.3	46.7	54.6	50.7	49.6	50.7	0.003	0.992
s.d	12.9	13.3	13.5	9.7	6.2	13.0	12.5		
Month	Kitchen								
	0	1	2	3	4	5	6	Wilks Lambda, probability value.	Partial Eta²
Mean	50.1	48.2	49.5	56.1	54.0	52.5	51.8	0.021	0.971
s.d	13.9	15.1	13.1	13.8	13.6	13.4	13.7		
Month	Table								
	0	1	2	3	4	5	6	Wilks Lambda, probability value.	Partial Eta²
Mean	49.6	49.3	46.8	53.9	51.1	51.3	57.9		0.998
s.d	13.8	13.8	13.5	14.3	12.9	12.6	17.5	0.0003	

Table 3.22: Errors sensors at individual locations across the timeline.

Month	Room (powered) (%RH)			Kitchen (powered)(%RH)	Table (unpowered) (%RH)
	Drawer	Wall	Seat		
0	**4.55 ± 1.3**	**4.96 ± 2.04**	**4.94 ± 1.77**	**4.39 ± 0.80**	**2.49 ± 1.51**
range	*2.65 - 6.42*	*2.93 - 11.02*	*0.37 - 7.22*	*3.24 - 5.65*	*0.03 - 4.81*
1	**3.05 ± 0.79**	**5.77 ± 5.07**	**2.08 ± 0.97**	**4.20 ± 2.26**	**2.78 ± 2.12**
range	*1.82 - 4.57*	*0.93 - 14.81*	*1.02 - 3.98*	*1.70 - 8.44*	*0.31 - 5.77*
2	**5.80 ± 1.98**	**6.14 ± 4.74**	**6.25 ± 6.18**	**6.00 ± 4.06**	**6.47 ± 5.86**
range	*4.04 - 12.01*	*0.49 - 16.48*	*0.03 - 18.33*	*1.36 - 15.59*	*0.03 - 17.10*
3	**3.42 ± 1.51**	**7.71 ± 5.41**	**9.31 ± 6.48**	**2.31 ± 1.92**	**3.06 ± 1.44**
range	*0.22 - 7.01*	*1.02 - 15.46*	*1.11 - 20.37*	*0.19 - 5.96*	*0.99 - 6.14*
4	**2.55 ± 1.35**	**1.96 ± 0.84**	**6.16 ±4.15**	**1.18 ± 0.91**	**2.69 ± 2.15**
range	*0.03 - 4.72*	*0.74 - 3.52*	*0.49 - 13.36*	*0.09 - 3.18*	*0.03 - 9.78*
5	**4.36 ± 1.90**	**4.05 ± 3.49**	**5.55 ± 2.28**	**2.46 ± 1.38**	**4.77 ± 3.26**
range	*1.57 - 8.77*	*0.43 - 15.09*	*3.39 - 13.00*	*0.71 - 6.05*	*1.05 - 13.86*
6	**4.98 ± 3.80**	**2.92 ± 0.80**	**4.11 ± 2.02**	**1.98 ± 0.71**	**3.94 ± 2.16**
	1.02 - 13.49	*1.08 - 3.92*	*0.15 - 8.55*	*0.40 - 3.21*	*0.31 - 7.84*
Total Mean	**4.10 ± 1.15**	**4.79 ± 1.98**	**5.48 ± 2.22**	**3.22 ± 1.69**	**3.74 ± 1.45**
Total range	***2.55 - 5.80***	***1.96 - 7.71***	***2.08 - 9.31***	***1.18 - 6.00***	***2.49 - 6.47***

Key: Errors between sensors at each location compared to the climatic chamber during monthly calibrations, data presented as mean samples ±1 standard deviation

Table 3.23. One-way between-groups ANOVA

Month 0	Mean	s.d	st.error	Levene's sig	ANOVA sig.	F-score: F (4, 40)
Drawer	50.51	13.6	4.5	1	1	
Wall	50.39	13.8	4.6			
Seat	50.39	12.9	4.3			
Kitchen	50.06	13.9	4.6			
Table	49.5	13.8	4.6	p > 0.05 so not violated and data is reliable	p> 0.05 so no difference	0.007
Month 1	**Mean**	**s.d**	**st.error**	**Levene's sig**	**ANOVA sig.**	**F-score: F (4, 40)**
Drawer	51.2	13.1	4.4	0.814	0.864	
Wall	44.6	17.4	5.8			
Seat	51.3	13.3	4.4			
Kitchen	48.2	15.1	5			
Table	49.3	13.6	4.6	p > 0.05 so not violated and data is reliable	p> 0.05 so no difference	0.319
Month 2	**Mean**	**s.d**	**st.error**	**Levene's sig**	**ANOVA sig.**	**F-score: F (4, 40)**
Drawer	47.3	13.1	4.4	1	0.989	
Wall	48.6	12.8	4.3			
Seat	46.7	13.5	4.5			
Kitchen	49.5	13.1	4.4			
Table	46.8	13.5	4.5	p > 0.05 so not violated and data is reliable	p> 0.05 so no difference	0.076

Month 3	Mean	s.d	st.error	Levene's sig	ANOVA sig.	F-score: F (4, 40)
Drawer	53.3	13.8	4.6	0.88	0.994	
Wall	54.5	12.3	4.1			
Seat	54.5	9.7	3.25			
Kitchen	56.1	13.8	4.6			
Table	53.9	14.35	4.8	p > 0.05 so not violated and data is reliable	p> 0.05 so no difference	0.056
Month 4	**Mean**	**s.d**	**st.error**	**Levene's sig**	**ANOVA sig.**	**F-score: F (4, 40)**
Drawer	51.1	12.7	4.23	0.273	0.977	
Wall	51.8	12.9	4.3			
Seat	50.7	6.2	2.1			
Kitchen	54.1	13.6	4.5			
Table	51.1	12.9	4.3	p > 0.05 so not violated and data is reliable	p> 0.05 so no difference	0.114
Month 5	**Mean**	**s.d**	**st.error**	**Levene's sig**	**ANOVA sig.**	**F-score: F (4, 40)**
Drawer	50.8	12.9	4.3	1	0.988	
Wall	52.3	12.4	4.1			
Seat	49.6	13	4.3			
Kitchen	52.5	13.4	4.5			
Table	51.3	12.6	4.2	p > 0.05 so not violated and data is reliable	p> 0.05 so no difference	0.079
Month 6	**Mean**	**s.d**	**st.error**	**Levene's sig**	**ANOVA sig.**	**F-score: F (4, 40)**
Drawer	50.6	13.4	4.5	0.726	0.783	
Wall	51.1	12.7	4.3			
Seat	50.7	12.5	4.2			
Kitchen	51.8	13.7	4.6			
Table	57.9	17.5	5.8	p > 0.05 so not violated and data is reliable	p> 0.05 so no difference	0.434

3.6 Study 4: Material comparison for encapsulating sensors

3.6.1 Study outline

Relative humidity sensors (HIH4000-004) were investigated by individually encapsulating them in seven different materials and comparing them to a sensor with no cover. The materials used were pore tape, thick HDPE plastic, thin LDPE plastic, a woollen glove, a surgical glove and a wheelchair seat cover they were all sewn into bags. The wheelchair seat cover is called 'Invacare deep' and it was used as a cover, and also sewn in to a bag to fit the sensor. The properties of these materials are in Table 3.24. Sensors were measured for 30 minutes in a climatic chamber set to 50 %RH. For analysis, the thirty minutes period was averaged and the arithmetical means are on Table 3.25. Difference between the sensors and the climatic chamber setting indicated under 'error between materials and chamber'. (Table 3.5: design for this study).

3.6.2 Results

Figure 3.19 shows the average output of the sensors with no cover and the rest with covers when measuring the climatic chamber setting of 50 %RH. The sensors with no cover (48 ± 2.2 %RH; range: 46 to 52 %RH) and with a cover (51 ± 0.2 %RH; range: 51 to 52 %RH) measured the lowest errors (no cover: 2.5 %RH; cover: 1.3 %RH). Higher errors were in the sensors encapsulated in bags (44 ± 0.74 %RH; 42 to 45 %RH; errors: 6.3 %RH) and the sensor in a woolly glove (44 ± 1.2 %RH; 42 to 54 %RH; error: 5.7 %RH). Figure 3.20 displays the errors between the sensors in material and the chamber. The worst performers were the sensors in bags with a cover: errors (16.2 %RH) (made from Invacare deep with an additional cover made from the material). Surgical gloves also had high errors: 13.8 %RH. Sensors encapsulated in thick plastic (11.4 %RH), thin plastic (12.8 %RH) and pore tape (12.2 %RH) yielded high errors that were slightly less than the surgical gloves. The room humidity was recorded using a multi-meter: 42 ±0.31 %RH (range: 41 to 43%RH). When the sensors were covered in all materials (except the Invacare cover) the Wilcoxon Signed Rank Test revealed a statistically significant reduction ($p < 0.05$) in humidity (compared to the 50%RH environment in the climatic chamber). This is confirmed on Table 3.25, which also shows the mean of the sensor with a cover is 1 %RH more than the climatic chamber setting ($p < 0.05$; (50 %Rh). On Table 3.26 all materials displayed a large effect except for the woolly glove. All materials displayed a significance level that was less than 0.05 ($p<0.05$): the difference (between each individual material and the sensor with no cover) was statistically significant. Which means that the scores for each pair (no cover versus sensor with a material cover) is different therefore the null hypothesis was rejected.

Table 3.24: Materials used in the experiment and the properties found in literature

Material	Material description	Thickness (mm)	moisture vapour transfer rate (mvtr) (g/m^2/24 hours (from literature)	MVTR measured at	References
HDPE thick plastic	High density polyethylene	0.08	4.7-7.8	38°C and 90 %RH	Polyprint 2008
LDPE thin plastic	Low density polyethylene	0.02	16-23	38°C and 90 %RH	Polyprint, 2008
Woollen gloves	100 % wool	1.14	230	-	Ireview gear.com, 2010
Clinical gloves	Polyvinyl chloride	0.1	2.4-4	38°C and 90 %RH	WHO, 2007
Pore tape	polyethylene film	0.25	400	40°C and 80% RH	EP0262786 A2 (1988)
Invacare Deep solution	Low density polyethylene	1	2170	100 °C and 90 %RH	Invacare, 2010; Ralston, 2010

Table 3.25: Descriptive statistics for the sensors surrounded by different materials at a single humidity.

Humidity (%RH)	No Cover	Covered	Bags	Bags and cover	Thick Plastic	Thin Plastic	Pore Tape	Surgical glove	Woolly glove
Mean	48	51	44	34	39	37	38	36	44
S.D	2.15	0.20	0.74	0.08	0.32	0.75	0.84	0.93	1.19
Min	46	51	42	33	38	35	35	34	42
Max	52	52	45	34	39	39	40	38	54
Error btw materials & chamber	2.5	1.3	6.3	16.2	11.4	12.8	12.1	13.8	5.7

Key: mean, standard deviation (S.D.), minimum and maximum output of sensors when measuring in the climatic chamber set to 50 %RH. The graph that represents this is Figure 3.19.

Figure 3.19: Output from encapsulated sensors at a relative humidity of 50% in climatic chamber

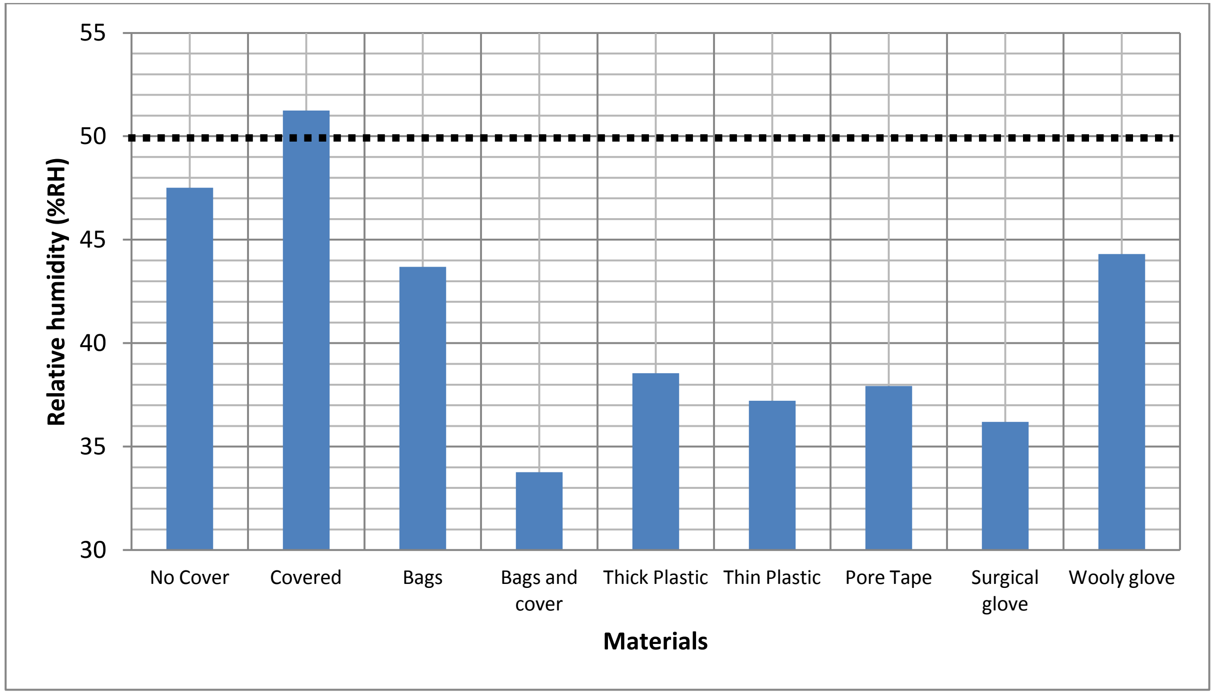
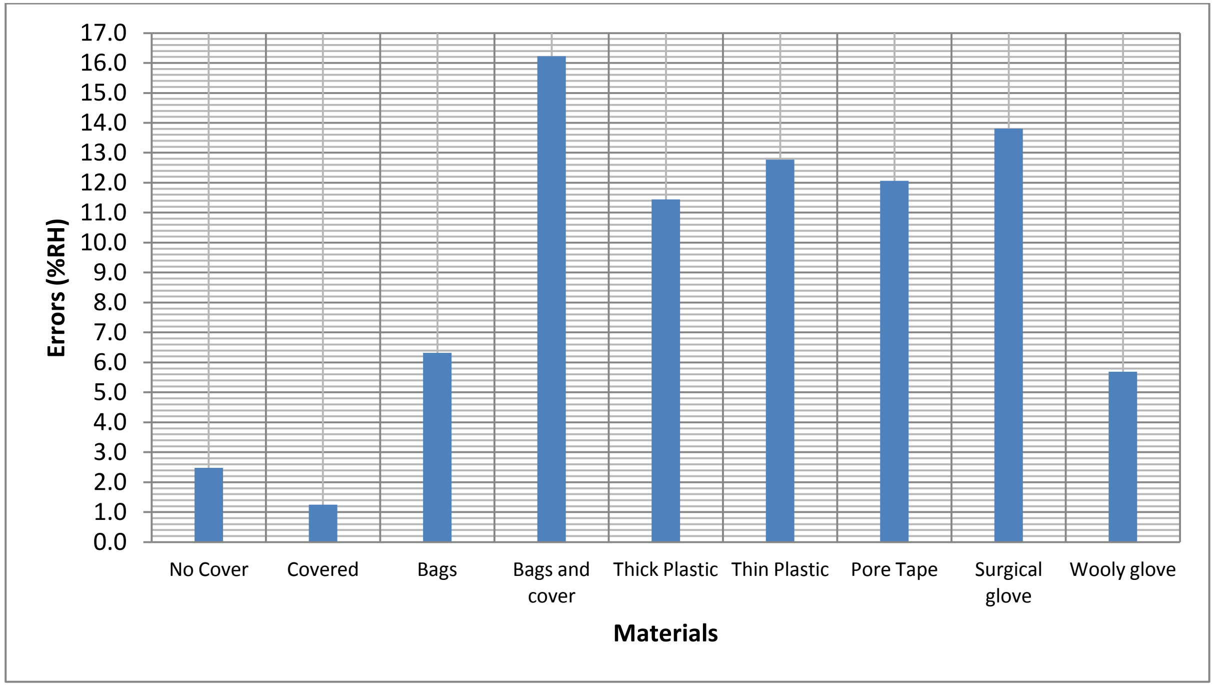


Figure 3.20: Error related to encapsulation, at a relative humidity of 50% in climatic chamber



Key: covered refers to encapsulation by polyurethane seat cover.

Table 3.26: Difference between materials tested.

Materials and humidity level exposure.	(Wilks lambda) Significant effect is p<0.05	z-score	Partial eta squared	Effect size
No cover vs Cover	< 0.001	25.173	0.795	large
No cover vs Bags	< 0.001	-27.420	0.866	large
No cover vs Bags with cover	< 0.001	-27.420	0.866	large
No cover vs Thick plastic	< 0.001	-27.420	0.866	large
No cover vs Thin plastic	< 0.001	-27.420	0.866	large
No cover vs Pore tape	< 0.001	-27.420	0.866	large
No cover vs Surgical glove	< 0.001	-27.420	0.866	large
No cover vs Woolly glove	< 0.001	-3.920	0.124	small

3.7 Study 5: Sensitivity of sensors on water detection

3.7.1 Study outline

A set of six humidity sensors (HIH4000-004) was used to collectively measure the environment of a laboratory in six different conditions. The six conditions were: sensors with no cover, sensors with a cover (Invacare deep plus), sensors with cover and water dropped on top, water dropped 1cm away from the sensor, water dropped 2 cm away and water splashed at a temperature of 37 °C (to simulate urine). The water drop of 0.05 ml volume is consistently dropped at a height of one inch above every sensor. Six sensors collectively measured each condition separately for 50 minutes. Six data sets were collected throughout this time scale for each condition. For ease of analysis, the six sensors were averaged, and at times 0, 1, 5, 10, 20, 30 and 40 minutes, 20 epoch points were sampled and their arithmetical means are displayed in Table 3.27. The room humidity was 44.6 %RH and temperature 25 ˚C. Table 3.5 contains the design of the study,

3.7.2 Results

The sensors with no cover reduce in humidity (1 %RH) after one minute. When the sensors were covered they record being lower humidity than with no cover (1 %RH lower). Within the first five minutes of water being dropped on top of the sensors a small increase in humidity was measured (45.3 %RH to 45.6 %RH), this condition measured similarly to the sensors having water splashed on (45.3 %RH to 45.7 %RH). During this initial five minutes, less humidity was detected when water was dropped one cm away (44.5 %RH ± 1.5 %RH) however when dropped at two cm away a higher humidity was measured (47.1 ± 1.9 %RH). After the five-minute period the output from sensors with water on top, 1 cm away or 2 cm away rose slowly over the remainder of the recording time (5 to 40 minutes). However for the sensors with splashed water, the sensor's output rose steeply for between 5 and 30 minutes from 45.7 %RH to 53.8 %RH (almost a 10 %RH change). Between thirty minutes and forty minutes the output remained stable at 53.8 %RH. The output from sensors in all conditions were averaged across the time period and the results can be seen in Figure 3.21, which was computed from Table 3.27. Between sensors with no cover and sensors with the direct introduction of water there was a significant difference ($p < 0.05$). The sensor's measuring ability appears to be affected differently in relation to differences in the introduction of water (dropping or splashing). Table 3.28 show the errors between the sensors with no cover and the sensors under the other five conditions. The sensors with a cover gave the lowest error (0.65 ± 0.36; range: 0.01 - 1.06 %RH). Water splashed on the cover gave the highest error (9.28 ± 4.30 %RH; range: 5.29 –

14.85) compared to the water dropped on at other distances (on top: 6.46 ± 1.04; range: 5.35 – 7.87 %RH; 1 cm away: 5.22 ± 0.79 %RH; range: 4.47 - 6.24 %RH; 2 cm away: 7.72 ± 0.7 %RH; range: 6.98 - 8.61). The differences can be seen in Figure 3.22 and 3.23. This figure clearly shows that the largest errors occur when sensors are splashed with water at 37 °C. Table 3.30 shows the results of the sensors at 50%RH to the maximum and its absolute and relative changes.

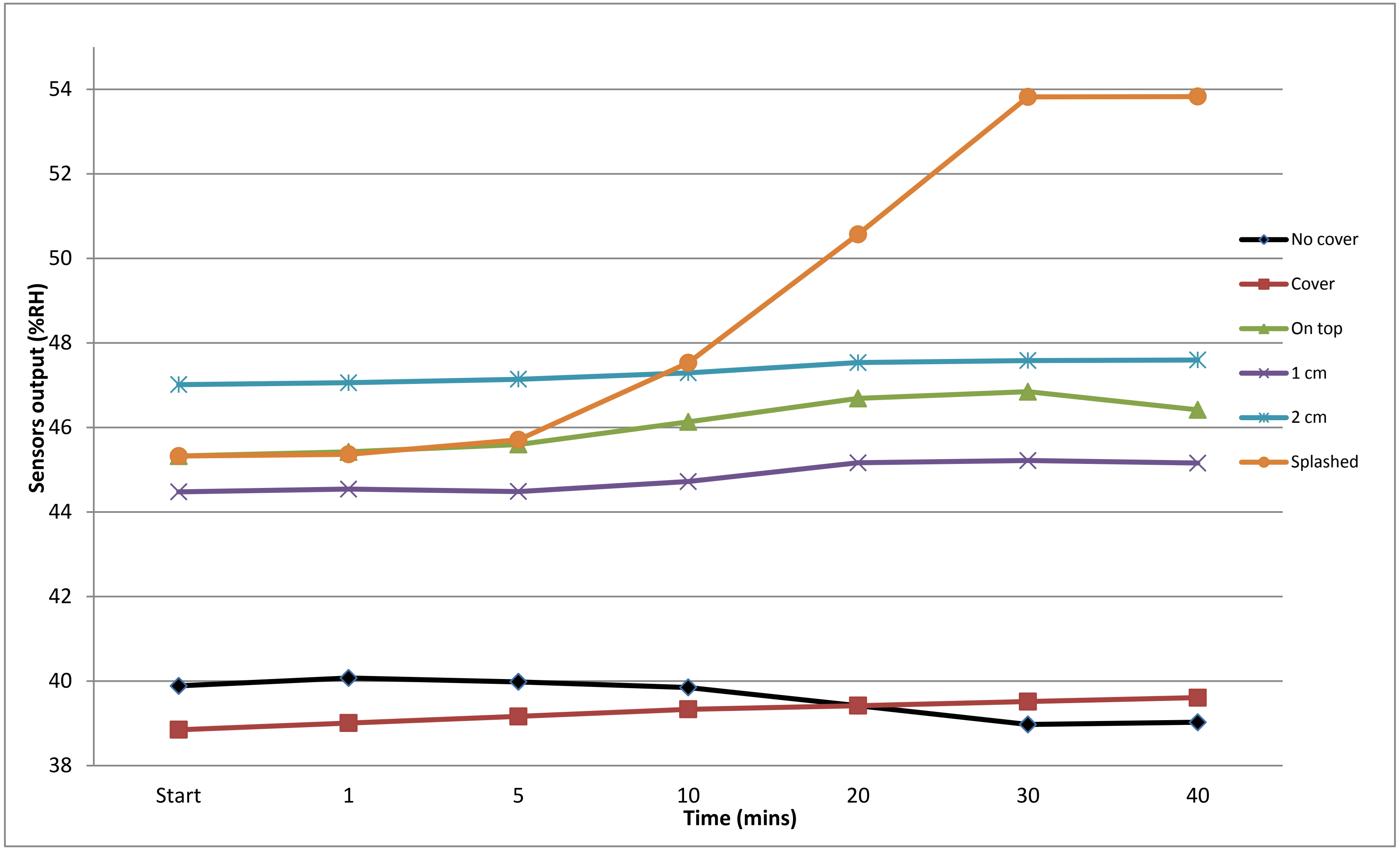
A paired samples t-test was conducted to evaluate the impact of the introduction of a cover and water dropped at distances when compared to sensors with no cover (Table 3.29). There was a statistically significant decrease in humidity (0.34 %RH) when the sensors with a cover (39.3 ± 0.3 %RH; $p < 0.254$, two-tailed) were compared to sensors with no cover (39.6 ± 0.5 %RH). The rest of the conditions on table 3.29 showed a statistically significant ($p < 0.05$) increase in output voltage compared to sensors with no cover. The mean difference and ranges are also displayed with a 95 % CI, the eta squared indicates the effect of the intervention (the introduction of a cover or water drops to the sensors) (Table 3.29). It may be concluded that for all interventions in this study there was a large effect with substantial difference in the humidity obtained before and after interventions.

Table 3.27: Descriptive statistics of sensor output across the experiment measurement period

Time	No cover				Cover				On top			
(min)	Mean	s.d.	Min	Max	Mean	s.d.	Min	Max	Mean	s.d.	Min	Max
0	39.9	1.3	38.6	42.4	38.8	1.8	37.6	42.3	45.3	1.5	44.1	48.1
1	40.1	1.4	38.7	42.8	39.0	1.7	37.8	42.4	45.4	1.5	44.1	48.3
5	40.0	1.3	38.8	42.4	39.2	1.7	38.0	42.5	45.6	1.5	44.4	48.5
10	39.8	1.3	38.6	42.4	39.3	1.7	38.2	42.7	46.1	1.1	45.0	48.2
20	39.4	1.2	38.2	41.8	39.4	1.7	38.2	42.8	46.7	1.0	45.6	48.2
30	39.0	1.4	37.7	41.7	39.5	1.6	38.4	42.6	46.8	1.0	45.8	48.3
40	39.0	1.4	37.7	41.8	39.6	1.5	38.5	42.5	46.4	0.8	45.5	47.4
Mean	39.6				39.3				46.1			
s.d	0.5				0.3				0.6			
min	39.0				38.8				45.3			
max	40.1				39.6				46.8			
Time	**1cm**				**2cm**				**Splashed at 37 °C**			
(min)	**Mean**	**s.d.**	**Min**	**Max**	**Mean**	**s.d.**	**Min**	**Max**	**Mean**	**s.d.**	**Min**	**Max**
0	44.5	1.5	43.4	47.3	47.0	1.9	45.8	50.7	45.3	0.4	44.8	45.7
1	44.5	1.5	43.5	47.4	47.1	1.9	45.8	50.9	45.4	0.4	44.7	45.9
5	44.5	1.4	43.5	47.2	47.1	2.1	45.8	51.2	45.7	0.7	44.6	46.7
10	44.7	1.2	43.7	47.1	47.3	2.0	45.9	51.3	47.5	1.7	45.4	50.3
20	45.2	1.2	44.2	47.4	47.5	1.8	46.2	51.0	50.6	3.1	46.2	54.2
30	45.2	1.0	44.3	47.0	47.6	1.6	46.3	50.7	53.8	4.8	46.4	60.2
40	45.2	1.1	44.2	47.1	47.6	1.6	46.3	50.8	53.8	4.8	46.3	60.2
Mean	44.8				47.3				48.9			
s.d	0.3				0.3				3.8			
min	44.5				47.0				45.3			
max	45.2				47.6				53.8			

Key: The data at each time point is the average of 20 stable data points (Min=minimum; Max=maximum; s.d= standard deviation; Min=minutes).

Figure 3.21: Sensors measuring a variety of conditions across a measurement period.



Key: Sensors exposed to different conditions; with no cover and then when a cover was introduced water was dropped : on top, 1 cm away, 2 cm away and then splashed all over at 37 °C

Figure 3.22: Averages of the complete time period for sensors measuring the conditions.

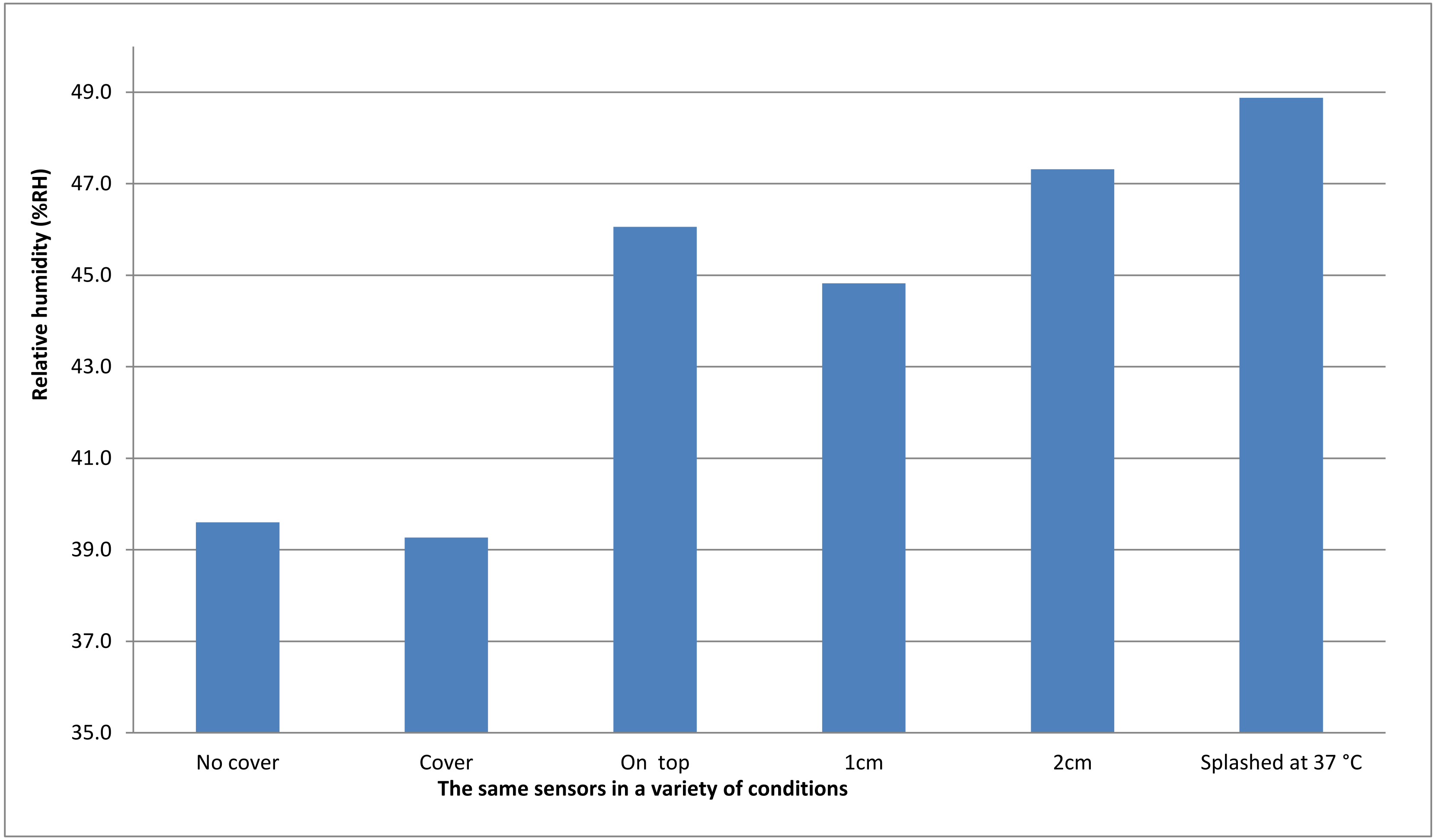


Figure 3.23: Errors between sensors measuring with no cover and the 5 other conditions

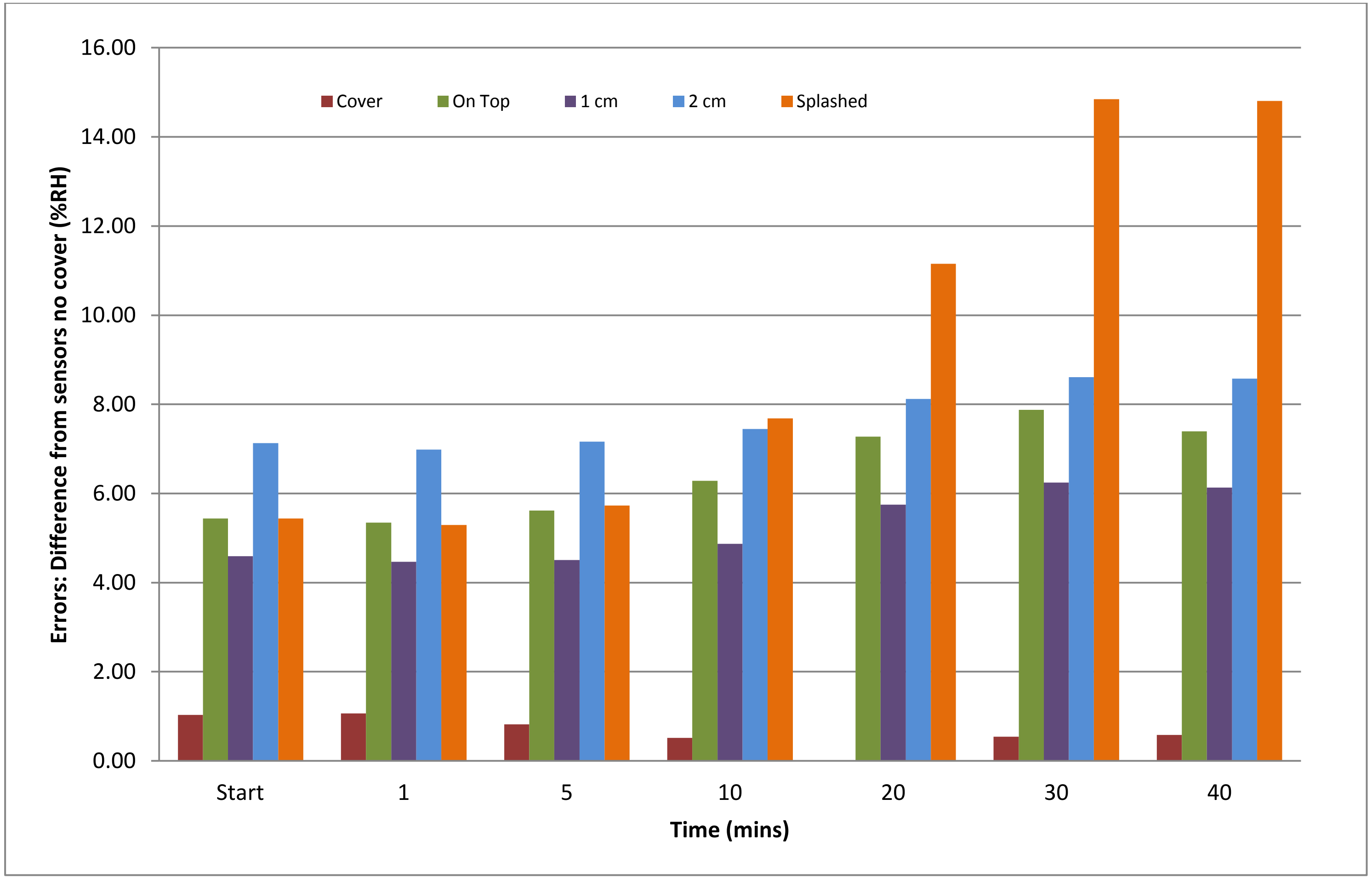


Table 3.28: Descriptive statistics relating the errors between sensor output: with no cover compared to the 5 other conditions

Time	Cover	On Top	1 cm	2 cm	Splashed
0	1.03	5.44	4.59	7.13	5.44
1	1.06	5.35	4.47	6.98	5.29
5	0.82	5.62	4.51	7.16	5.73
10	0.52	6.28	4.87	7.44	7.68
20	0.01	7.27	5.75	8.12	11.15
30	0.54	7.87	6.24	8.61	14.85
40	0.58	7.39	6.13	8.57	14.81
Mean	0.65	6.46	5.22	7.72	9.28
s.d	0.36	1.04	0.79	0.70	4.30
min	0.01	5.35	4.47	6.98	5.29
max	1.06	7.87	6.24	8.61	14.85

Table 3.29: Paired samples t-test results (no cover compared to the other conditions)

n=7	Sig (2 tailed, 95%CI)	p-value	Difference	t-test	Mean scores (No cover = 39.60 ± 0.47)	s.d	Mean difference	eta squared	effect
Cover	< 0.254	p>0.05	No difference	1.263	39.2571	0.28	none	0.21	large
On top	< 0.001	p<0.05	There is a significant difference	-16.23	46.0429	0.62	sig.increase(6.44)	0.98	large
1cm	< 0.001	p<0.05		-17.08	44.8286	0.35	sig.increase(5.23)	0.98	large
2cm	< 0.001	p<0.05		-28.73	47.3143	0.25	sig.increase(7.71)	0.99	large
Splash	< 0.001	p<0.05		-5.707	48.8714	3.83	sig.increase(9.27)	0.84	large

Key: No cover was used to compared with the other conditions

Table 3.30. Results for sensors

Sensor condition	*Time to max in minutes* (%RH)	*20mins (50% to max)*	*Absolute Change (RH %)*	*Relative Change (%RH)*
No Cover (No water)	1 (40.1 %RH)	39.4	0.9	2.3
With Cover (No water)	40 (39.6 %RH)	39.4	0.8	2.1
Water on top	30 (46.8 %RH)	46.7	1.1	2.4
Water 1cm away	20 (45.2 %RH)	45.2	0.7	1.6
Water 2 cm away	30 (47.6 %RH)	47.5	0.6	1.3
Splashed at 37 °C	30 (53.8 %RH)	50.6	8.5	18.8

3.8 Discussion

The studies in this chapter were carried out to expose the sensors to the moisture conditions that may be expected during sitting (Table xx reasons??). Testing was carried out in stringent environments allowed the characteristic behaviour of the sensors to be studied in response to controlled moisture conditions. This section discusses the results from these studies followed by the conclusions and limitations. Since the climatic chamber was used to address the reliability and accuracy of sensors (due to its calibration being traceable to national standards), the outcomes of these experiemnts can be used to better understand the factors that may affect output of the humidity sensors when measuring human subjects. The following chapter will address the use of the same sensors in the measurement of humidity from human subjects.

Measurements in the climatic chamber were performed in multiple runs within a period of almost one year. This time line was necessary to facilitate the five studies carried out in this chapter. Pilot tests were also carried out to ensure suitable assembly and verification of the experimental setups prior to the deployment of the five studies. This involved time consuming and rigorous sensor testing measuring different humidity and temperature levels in the climatic chamber. As part of the pilot testing, the sensors measured a humidity profile (between 30 %RH and 70 %RH) at four temperatures (15 °C, 20 °C, 25 °C and 32 °C). Regression analysis showed that the humidity profile measured the best fit (R^2 = 1) at 20 °C and 25 °C. Since the manufacturer's calibration is carried out at 25 °C, this was the chosen temperature setting for all experiments in this study (Honeywell, 2014). The HIH4000 Honeywell humidity sensors consistently measured below the climatic chamber setting (traceable to national standards) and therefore regression factor analysis was incorporated to adjust the signal by producing a correction equation. When the correction equation was applied to the sensors output the maximum errors were within (0.4 ± 0.2 %RH; range: 0.2 to 0.6 %RH) the limits of the manufacturer's datasheet (± 3.5 %RH at 25 °C). The humidity sensors were the main focus in this study; however the temperature sensors were also calibrated for reference. The errors produced from calibration were also within (± 0.3 °C) the limits of the LM35 manufacturer's data sheet (± 0.75 °C). Within the climatic chamber initial humidity level discrepancies were caused by problems with condensation in the tube supplying air to the reference sensor which caused long transition times of the chamber between different humidity and temperature settings (Vacek, 2009). Allowing the chamber to settle for a period of up to 45 minutes before testing was carried on a new day was crucial for stable internal humidity environments.

Even though the HIH4000 Honeywell (capacitive polymer) humidity sensors measure a wide range of humidity's (0 %RH and 100 %RH), it was important to decide on the testing limits so that the results could be related to the application of human sitting and incontinence detection. This was done by highlighting published humidity limits advised for human comfort. According to Health and Safety Executive (HSE, UK), the humidity of between 40 %RH to 70 %RH in the work place environment is advised to not affect human thermal comfort. However it has been reported by the American Society of heating and ventilation engineers (ASHVE) that the body feels comfortable at a temperature 27.7˚C (summer), 22˚C (winter) as long as the humidity is between 35 and 65 %RH. The Canadian standards advocate that a comfortable work or home environment should be between 30 %RH and 60 %RH in the winter (20 – 25.5 ^{o}C) and summer 23 – 28 ^{o}C. Based on this the author decided that the HIH4000 Honeywell humidity sensors should be tested at a humidity profile between 30 %RH and 70 %RH at 25 ^{o}C. This was ideal because exposing the capacitive polymer sensors more than 70 %RH has been reported to cause deviations more than acceptable (Griesel, Niemand and Lanzinger, 2012; Matsuguchi et al., 2000). Table 3.31shows the outcome of the hypothesis and the answer to the research questions.

Table 3.31: Outcome of hypothesis and answers to the research question.

Title	
Study 1	Comparing the performance of existing and new sensors
Hypothesis	There is no difference between the existing and new sensors
Outcome	Rejected: There was a significant difference between the existing set and brand new set of humidity sensors ($p < 0.05$; two-tailed).
Results	The brand new sensors had low errors (2.16 ± 1.3 %RH; range: 0.12 %RH to 4.21 %RH) and followed the climatic chamber humidity profile indicating stability in its performance. The large errors between the existing sensors (9.45 ± 5.2 %RH; range: 0.9 %RH to 20.2 %RH) and the chamber indicate that the measurement ability of the sensors may have been affected by usage.
Research question	Research question: Would sensors with 2 years of usage perform different to brand new sensors? Answer: Yes however it may not be known how the usage could have caused the existing sensors to perform worse than the brand new sensors.
Discussion	The results of this study show that a difference was found between the brand new set of sensors and existing used sensors. The existing set of sensors performed worse and this may be due to experimental usage that took place between 2008 and 2010 for the purpose of publication. The deterioration in performance of the existing sensors shows how important it is to check and re-calibrate sensors. If two years of usage caused a noticeable difference in performance when compared to a new set of sensors then perhaps more frequent calibration times would be necessary. For the purpose of incontinence detection, it is envisaged that the sensors would have consistent contact with a subject, so the effects of consistent exposure of humidity to humidity sensors need to be investigated.
Limitations	The handling and storage of sensors were not reported by the previous users so it is difficult to describe how deterioration occurred. Although the existing sensors (HIH4000-003) and brand new sensors (HIH4000-004) sensors were not the same model the only difference between them was the slope and the response time (based on the manufacturers data). It would be interesting to test the same model in future. It is also unknown whether moisture accumulation on the sensors due to experimental usage could cause deterioration in accuracy. The experiments reported by the published studies (McCarthy et al., 2009; Cascioli et al., 2010), show a significantly high amount of usage; however the preparations for pilot testing or storage protocols prior to publication have not been reported. Therefore it is not known how this could have affected the performance of the existing sensors.
Study 2	Sensor verification experiment after exposure to desiccant
Hypothesis	There is no difference between the new sensors before and after drying them.
Outcome	Rejected: There was a significant difference between the sensors before and after they were dried ($p < 0.05$; two-tailed).
Results	For the whole of the humidity profile the errors between the sensors before and after they were dried were found to be 2.8 ± 1.7 %RH (range 1 to 8 %RH). During calibration the sensors before drying measured lower than the climatic chamber (indicated by the negative sign as being lower than the chamber setting): -1.68 ± 2; range: -4.17 to 3.14. After drying, the sensors measured a mixture of lower and higher than the chamber settings: 0.61 ± 3.71 %RH; range -5.61 to 7.56 %RH. Least errors were found for both before and after between the 40 %RH ascending and 40 %RH descending scale: Before drying (-2.24 ± 1.6; range: -4.17 to 1.63) and after drying (-1.34 ± 2.18; range -5.16 to 2.06).
Research question	Research question: Would sensors perform differently after exposed to a desiccant? Answer: The new sensors generally performed better after being exposed to the desiccant. It was envisaged that if the drying agent could remove that much humidity it may have removed the moisture from the sensors.
Discussion	When the same set of sensors are exposed to humidity before and after being dried in a desiccant environment, they both appear capable of measuring the environmental air and also a controlled environment of the climatic chamber. Drying out the sensors by exposing them to a desiccant for 48 hours made them more sensitive to detection of humidity. It may be concluded that the desiccant successfully dried out the structure of the sensor itself thus increasing its accuracy.
Limitations	The desiccant used in the authors study was the same desiccant used in the McCarthy et al., (2009) study. Although the author re-calibrated the desiccant, it would have been interesting to use a new batch of desiccant. In the McCarthy et al., (2009) study the desiccant brought the same sealed environment down to 3.1 ± 0.2 %RH where as this study brought it down to 22.9 ± 0.3 %RH. This indicates that the desiccant may have reduced in effectiveness through time and previous usage. Recalibration of the desiccant may not have re-set its drying properties.

Study 3	Endurance of humidity sensor with respect to time and location
Hypothesis	1) There is a difference between sensors in different locations. 2) There is a difference between sensors measured over 7 months.
Outcome	1) Rejected: There was no statistically significant difference found ($p > 0.05$). 2) Rejected: There was no significant difference found ($p > 0.05$).
Results	1) Based on the statistical analysis the sensor placed in the kitchen may have had the most deterioration over time and interestingly the sensor in the seat that had constant contact with a subject deteriorated the least. However according to the raw data on the errors between these two sensors and the climatic chamber, the results found was opposite: the seat sensors performed with most errors and the kitchen the least. Interestingly the unpowered sensors do deteriorate when unused. 2) The errors between the sensors and climatic chamber were similar across the six months (errors- drawer: 4.10 ± 1.15; range: 2.55 - 5.80; wall: 4.79 ± 1.98; range: 1.96 - 7.71). The sensor embedded in a seat did have significant differences ($p < 0.05$) between months 1 and 2 and also months 1 and 5 (error- seat: 5.48 ± 2.22; range: 2.08 - 9.31). The kitchen sensor revealed the most differences (ten times across the months). However had the least or errors when compared to the climatic chamber (errors- kitchen: 3.22 ± 1.69; range: 1.18 - 6.00). The unpowered sensor revealed fewer differences (6 times across the months) with slightly more errors than the kitchen sensor (table: 3.74 ± 1.45; range: 2.49 - 6.47).
Research question	Research question: Would the performance of brand new unused sensors deteriorate over time and would location affect their ability to measure over time? Answer: This the location of the sensors did not affect their ability to measure over time when continuously powered
Discussion	When it measured a stable environment in these two locations there was no apparent deterioration over the seven months. This may indicate that for a period of 7 months the environments whether dry or heavily humid did not affect the sensors measuring capabilities (room temperature and humidity recordings in Appendix 1e). When the sensor was exposed to a subject during constant sitting only two counts of difference were found across the seven months. The unpowered sensors did deteriorate when unused. The kitchen may be different because it was located in a different room to the other 4 sensors. Perhaps exposure to higher humidity such as in a kitchen environment; exposure to kettle steam, water from the sink, food and usage of microwave as well as movement of people may increase the general humidity in this environment. It may be interesting to point out that perhaps these sensors may need protection; therefore encapsulation within a material may protect them.
Limitations	The housing of the sensors was basic and each had to be checked daily to ensure the sensors were continuously powered (except weekends). The sensors in the seat moved with the person as they re-shifted for comfort. A few times (five times) the sensors detached from the battery connection. To solve this, the housing was changed and the sensor was re-soldered to the sensor boards with new wiring. There were no problems of detachment after this (before month 2's calibration) however the specific differences in effects of the new housing and re-soldering are unknown.
Study 4	Material comparison for encapsulating sensors
Hypothesis	There is no difference between a sensors measuring with no cover and through a variety of materials.
Outcome	Rejected: there was a statistically significant difference found ($p < 0.05$)
Results	Sensors encapsulated in bags with a general cover (error: 16.2 %RH; both made from Invacare deep plus material) performed the worst. This was followed by surgical gloves (13.8 %RH), thick plastic (11.4 %RH), thin plastic (12.8 %RH), pore tape (12.2 %RH) with high errors. The errors reduced when sensors were encapsulated in the Invacare deep plus bag (6.3 %RH) and the woolly glove (5.7 %RH). The lowest errors were found in sensors with no cover (2.5 %RH and with a cover (1.6 %RH). These two sensors were the best performers because their errors fall within the accuracy of the manufacturer's data for Honeywell HIH4000-004 sensors (±3.5 %RH). Therefore the sensors with no cover and then with a cover provide the most reliable measurement.
Research question	Is there a suitable material that can protect sensors and allow them to make reliable measurements?
Discussion	Uncovered or covered (but not encapsulated in a bag) sensors measure differently than when they are encapsulated in a material. The output from the sensors can be used to discriminate between different materials as indicated by the errors found. The worst performers were sensors encapsulated in either impermeable products such as surgical gloves, plastic, pore tape, or materials which are thick (presenting a large distance for water vapour to traverse) such as woolly gloves. A wheelchair seat cover designed to a high standard of engineering, performed the worst when it was sewn in to a bag for the sensor to be encapsulated in. obviously, it performed even worse when the same material was placed over this encapsulated sensor. Although interestingly when the sensor was taken out of the bag and covered in just the Invacare cover it yielded the lowest error. Sensors performed well with no cover too, performing within the manufacturer's acceptable limits. This study indicates that sensors are able to measure when within an encapsulated bag; however, it might be that the dimensions were a limiting factor in measurements. This aspect was not subjected to experimentation in this thesis.
Limitations	Instead of focusing on materials that are used in general life, it may have been more appropriate if the sensors were encapsulated in a variety of specialised covers sewn into bags with larger

	dimensions. It would have been interesting to see if the thickness of the Invacare deep plus cover and sewing technique could have reduced the errors of measurement
Study 5	Sensitivity of sensors on water detection
Hypothesis	1) There is no difference when sensors measure ambient air. 2) There is no difference when water drops are introduced.
Outcome	1) Rejected: there was no significant difference found ($p > 0.05$). 2) Rejected: there was a significant difference found ($p < 0.05$).
Results	A change in mean score was seen when the sensors with no cover (39.6 ± 0.5 %RH) were compared to the covered sensors (39.3 ± 0.3 %RH), water dropped on top (46.1 ± 0.6 %RH), water dropped 1 cm away (44.8 ±0.3 %RH), water dropped 2 cm away 47.3 ± 0.3 %RH) and water splashed at 37 °C (48.9 ± 3.8 %RH). This clearly indicates that the sensors are affected differently in different conditions especially in relation to the introduction of water.
Research question	Are the sensors able to detect moisture from different distances?
Discussion	Water dropped at 1cm away and 2cm away was detected. Between sensors with no cover and sensors with the introduction of water there is a change. Sensors are able to discriminate between different water dropping and splashing conditions. It may be concluded that for all interventions in this study there was a large effect with substantial difference in the humidity's obtained before and after the introduction of more moisture
Limitations	Due to only one cover being used for this experiment, the wet covers were dried out for one night before recommencing with further experiments. More than one cover would have helped this.

3.9 Conclusion

Existing sensors used to measure humidity for a year including sitting tests in a published study showed signs of ageing. Brand new sensors that were continuously powered and calibrated once a month over seven months showed minimal changes. These new sensors appeared to show no deterioration when placed in a dark place or exposed to light, or even when a subject sat on one sensor everyday (except weekends and sick leave) during the period of seven months. Humidity output from the sensor in the kitchen showed some degree of change due to being directly exposed to steam over a frequently used kettle. High exposure to humidity from the steam of the kettle affected the sensors although it is not known how incontinence could affect the sensors at a sitting interface. Generally when a pad receives the urine volume it is readily absorbed into the core and spreads from the entry point to the rest of the absorbent material. Secure storage of urine prevents leakage until the pad has changed. Leaks would normally occur when the spread of urine exceeds the capacity of the pad storage ability (Cusick et al., 2003; Landeryou, Yerworthand Cottenden, 2003). The urine leak would initially dampen clothes causing an increase in the humidity of the microclimate at the person and seat interface. This is why the concept of measuring humidity externally to detect urine leaks or incontinence due to increased sitting humidity's is the main interest in the author's research. Although in relation to pad leaks the fluid direction, orientation of pad and pad material are affected during mechanical loading caused by sitting and have been the subject of research (Cusick et al., 2003; Landeryou, Yerworthand Cottenden, 2003). Problems with current UI detection sensors include false triggering, expensive fabrication techniques, and additional cleaning. Measuring levels of humidity at the sitting interface requires carefully study on sensitivity to water vapour. A difference in humidity was detected by individual sensors when of water was dropped (0.5 ml per water drop) at different distances (no water, water dropped on top, 1cm away). The sensors detected higher humidity's when urine simulation was carried out by splashing heated water (37 °C) over the sitting cover (20 ml of water at a height of 3 inches). As long as multiple sensors are used (Cascioli et al., 2011; McCarthy et al., 2009), the embedded humidity sensors are able to successfully differentiate between water drops (0.5 ml) and also urine leak simulation (20 ml). This suggest that the exact changes in humidity due to the presence of moisture from incontinence could be detected regardless of the exact seating position (this is the case when sensors are embedded in three locations the coccyx and both thigh regions). Humidity is also able to penetrate through materials fast therefore water vapour could be detect before liquid is present (NPL, 2012). Investigating HIH4000 Honeywell sensors over time has shown that even with increased exposure to moisture performance could get affected. It had been advocated that drying sensors coupled with periodic calibration could prolong the life of sensor performance however the addition of a protective insulation cover could protect this even further. When different material were tested the Invacare cover was thought to perform best due to its transpiration properties however it performed the worst when sewn into a bag. As a normal cover it is designed for the dynamics of sitting therefore when sewn into a bag the thickness may not allow for sufficient breathability when surrounding a sensor. If the wheelchair cushion cover technology was used to create something with a thinner membrane the measurement quality may differ. If this can be achieved then it would be ideal to set up sensors that are bagged in appropriate materials, and this could prolong the life span of the sensors, avoiding direct contact with human excrements allowing cleaning of material therefore sensors may be transferred between patients so infection control regulations are complied. When the HIH 4000-004 Honeywell humidity sensors are embedded within a seat, they are able to detect humidity and show little sign of drift and although they may reduce in sensitivity over time (7 months to year after usage). Periodic re-calibration once a year couple with techniques to dry sensors would certainly prolong the life of the sensors and maintain accuracy and reliability in measurement. Furthermore carefully designed insulation will protect the polymer surface from additional dust and water vapour contamination and minimise the need for additional cleaning. This article concluded that the behaviour of each cushion is influenced strongly by the coverings used as well as by the primary structural material. Further work would be required to use actual incontinence situations to test the humidity sensors and investigate the cost of the system.

Chapter three demonstrated that humidity sensors may reliably measure moisture in a variety of conditions, such as when introduced a distance away, when encapsulated in certain materials either in a bag or under a seat cover. Furthermore, the regular re-calibration of sensors (traced to National standards) indicated that these sensors could sufficiently accurately quantify difference between various water vapours concentrations expected to be found associated with the incontinent person. It can also be concluded that humidity sensors, maintained through routine exposure to drying environments, should be able to function over prolonged periods of time (>7 months). By exposing the sensors to re-calibration these sensors should be sufficiently reliable to be used in monitoring incontinence events in human subjects. The studies in chapter 3 provide data that will enable the design of suitable experiments to study these sensors in the role of assessing relative humidity change at the seat surface between a human subject and the seat.

Chapter 4

Application of the sensors in a simulation of care home sitting activity

"It was one of those humid days when the atmosphere gets confused. Sitting on the porch, you could feel it: the air wishing it was water." - Jeffrey Kent Eugenides.

Testing the humidity sensors in a controlled environment (traceable to National standards) has provided an understanding to their reliable and accurate measurement characteristics. This means that sensors that are calibrated can be dependable when measuring outside the laboratory environment. Dementia residents in care homes spend large amounts of time sitting. To understand what happens at the sitting interface, this chapter explores the humidity measurement of healthy human subjects using humidity sensors located external to the body. As demonstrated in chapter 3, humidity is able to penetrate through layers of material which contains micropores. If a seat cushion is covered in such a material, levels of humidity can be detected when the sensors are embedded in, or around the seat cushion. This non-invasive and discrete method of humidity measurement would be ideal for discretely monitoring seated dementia residents. The interface between the person and the seat surface causes a build-up of humidity which in turn can raise the water vapour pressure next to the skin. The studies in this chapter aim to demonstrate that the humidity sensors are able to detect this microenvironment: demonstrated through prolonged and intermittent sitting experiments. The consensus is that it is possible to study the tissue response and distress causing skin breakdown at bony prominences by monitoring humidity at the person-seat interface.

4.1 Introduction to measuring humidity in sitting

The interaction between the seat surface and skin during sitting has been highlighted as an important factor in the prevention of soft tissue damage (Fisher et al., 1978; Stewart and Cochran, 1980; Ham, Aldersea and Porter, 1998; Hampton and Collins, 2004). Soft tissue breakdown not only occurs due to shear forces and abrasion in sitting, but factors such as temperature and moisture which appear to accelerate this process (vide supra) (Hampton and Collins, 2004; Wounds International, 2010). The interface between the person and the seat surface causes a build-up of humidity which in turn can raise the water vapour pressure next to the skin (Ferguson-Pell et al., 2009; Cheung, 2010). Figure 4.1 shows the aspects of the human body when in sitting (Cheung, 2010; Waugh and Grant 2001; NHS choices, 2009). Due to the nature of a seat and its cover there may be a reduced vapour gradient existing between the skin and the environment resulting in reduced evaporation (Cheung, 2010). As perspiration increases, there is a reduction in the capacity of evaporation to remove heat energy and this means that most of the sweat drips from the body and gets trapped within the fabric fibres of clothing and seat (Das et al., 2007; Ferguson-Pell et al., 2009). The water vapour permeability of the interfacing surfaces such as seats covers or clothing due to a person sitting may be significantly quantified by the dynamic nature of heat transfer rates (Goldman and Kampmann, 2007). High humidity and moisture at the sitting interface may increase susceptibility to conditions such as pressure sores especially in prolonged sitting durations. In terms of comfort perceptions by seated individuals, it has been suggested that physical measurement of temperature at the body seat interface may play an important role for assessing these perceptions (Cengiz and Babalik, 2007; Brooks and Parson, 1999; Liu et al., 2011). In car seat comfort studies, the driver's perceptions on thermal comfort were found to be depended on skin surface temperature and moisture accumulation (Paul and Sckert, 2003). Patient support systems (PSS) such as cushions play an important role in the dissipation of heat and moisture away from the seat interface which is necessary in order to maintain the physiological skin microclimate (Nicholson, 1999). The cover on the support surfaces is reported to greatly influence the skin temperature depending on the location on contact surface (Posana-Moreno et al., 2011) this also influences perspiration. The most important factor determining seat thermal comfort has been reported to be the cover laminate and the foam cushion acting as a barrier to perspiration (Fung and Parsons, 1995). With the right seat and cover combination it may be possible to remove surplus heat (thigh, buttock and back) (Madsen, 1994) and also by inference limit the moisture build-up.

4.1.1 i Measuring the seat person interface with humidity sensors

Since the skin is the potentially exposed part that can be measured in sitting, the consensus is that it is possible to study the tissue response and distress causing skin breakdown at bony prominences by monitoring the surface temperature and humidity (Stockton and Rithalia, 2007; McCarthy et al., 2009; Cengiz and Babalik, 2007). Many studies have used temperature and sometimes humidity sensors to study the microclimate at the seat-person interface although these studies have varying methodologies and sample sizes.

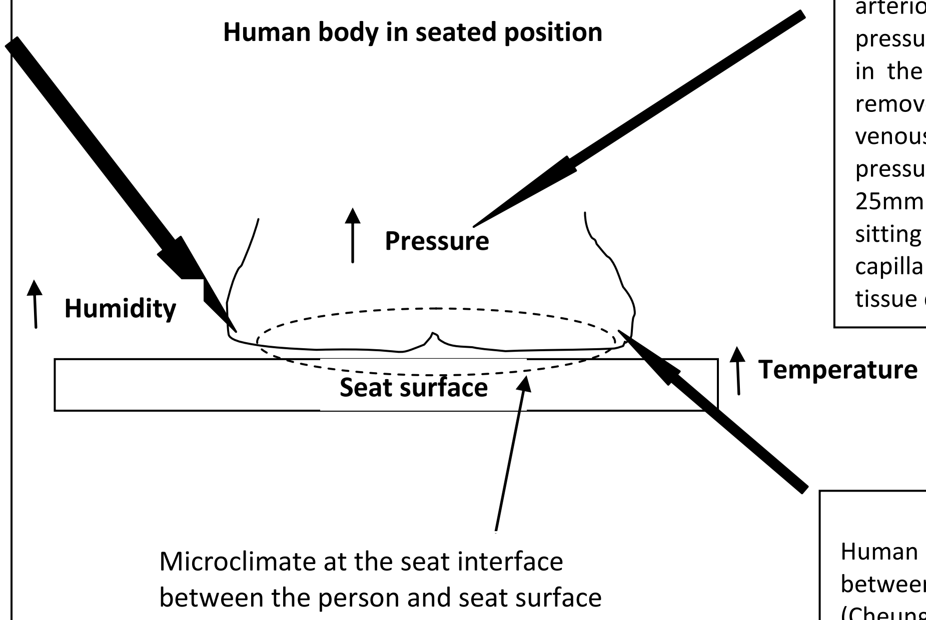
Figure 4.1: Aspects of skin integrity and sitting

Humidity

If ambient air temperature is equal to skin, heat exchange via radiation, conduction and convection is minimised. The main heat dissipation avenue is evaporation from secreted sweat. Less water particles in the air: easy evaporation. Higher the humidity the harder it is to sweat (Cheung, 2010). Humidity at the skin support interfaces; should ideally be between 40-65% and interface temperature should not change by more than a few degrees. In a clinical study on humans on support surfaces the RH% under seat buttock may vary between 40-100% and temperature on the Ischial tuberosities vary between 30-37˚C (Nicholson, *et al.,* 1999).

Heat loss: In a resting individual the total heat loss from the body surface of 1.8m² is 64W/m² and the moisture vapour flow through the skin per day is 0.40kg/m² Ferguson-Pell,*et al.,* (2009).

Sweating: Sweat and excessive sweat condition (hyperhydrosis) causes excess moisture at the seat microclimate which can affect skin integrity making individuals more prone to infection and dehydration (Nhs choices, 2013).



Pressure: Blood Perfusion

O_2 is diffused from the blood into the cells at the arteriole end of the capillary bed at a hydrostatic pressure of 35mmHg (5kPa). The osmotic pressure in the capillaries is about 25mmHg (3kPa). CO_2 is removed from the cells and into the blood at the venous end of the capillary bed at a hydrostatic pressure of 15mmHg (2kPa) and osmotic pressure is 25mmHg (3kPa) (Ferguson-Pell *et al.,* 2009).At the sitting interface a pressure of 32mmHg is enough for capillary closure and it is generally the indication for tissue damage (Landis, 1930).

Temperature

Human maintain constant body temperature between 36-37.5˚C, independent to the environment (Cheung, 2010). In still, ambient temperatures at 20˚C, the skin surface temperature when clothed is between 31˚C and 36˚C Ferguson-Pell,*et al.,*2009). Increases in skin temperature induce a sweat response increasing the potential for moisture to accumulate at the microclimate of the seat interface (Reger, 2005).

The methods used for sensor positioning include seat or skin attachment and simulation studies, making it challenging to compare the literature (Rithalia and Stockton, 2007; Cengiz and Babalik, 2007; McCarthy et al, 2009; Liu et al, 2011; Posana - Moreno et al., 2011; Vlaovic, Domljan and Grbac, 2012).

4.1.1 ii Sensors attached to seat

Humidity and temperature sensors placed in the core of the cushion (during sitting) showed that high temperature or high humidity was not necessarily linked with discomfort, and comfort was not necessarily linked to lowest interface pressures (Rithalia and Stockton, 2007). When five pairs of temperature and humidity sensors were embedded in a wheelchair seat cushion (specific locations: under the ischial tuberosities (IT's), thighs and coccygeal regions) the magnitude of change in temperature and humidity appeared to be related to the anatomical positions (McCarthy, *et al.,* 2009). However measurements under the thighs and IT's were similar and so the numbers of sensors were reduced to three locations in a seat cushion to the thighs and coccygeal region where differences were detected. The measurements at these new locations had significantly different recorded humidity ($p < 0.01$) allowing valuable comparisons to be made between regions. The measurement output of the sensors at their respective positions and same seat surface were highly correlated between subjects ($r > 0.99$) making it more consistent for proving that the three positions were appropriate and necessary for detailed study on skin surface temperature (Liu et al, 2011). In another study sensors were placed inside the cushion to compare the seat and back of chair: warmer sensations were reported under the buttocks and thighs. However it was suggested that testing should be longer than 90 minutes to reinforce these results. The probes used were large therefore embedding in seats would be necessary to avoid movement (Vlaovic, Domljan and Grbac, 2012, Liu, et al., 2011). Sensor placement is crucial for assessing variables being measured since it has been reported that magnitude of measurement is related to anatomical location of sensors (McCarthy et al., 2009). Embedding sensors makes it part of the seat and it is believed that it will reduce pressure effects, contamination from skin conditions, allow a fixed sensing range and also not be an influence in the sitting profile or perception of comfort or discomfort (Mutlu et al., 2007; McCarthy, *et al.,* 2009). Since there are differences between the anatomical locations during sitting, the use of multiple sites for sensor placement may be more beneficial than a single site when studying these parameters at the interface between subject and seating material at the seat base (McCarthy et al., 2009; Liu et al., 2011). Table 4.1 displays the variety of sitting studies carried out to detect humidity and temperature in human participants.

4.1.1 iii Sensors attached to the human skin

Sensors attached to the human body may be able to monitor the surface temperature and humidity effectively (Stockton and RIthalia 2007). In particular thermistor probes have also been used to evaluate the temperature at the seat interface under the IT's and coccygeal area (Stewart et al, 1980; Finestone et al., 1991). However sensors that are in contact with the body may cause a local increase in temperature and accumulation of moisture at the sensor skin contact. Furthermore, the attachment of sensors on skin may influence how the person may sit especially if the sensors do not feel comfortable on the skin (Liu et al., 2011). In addition to this sensors may move with the skin (Stewart et al, 1980; Finestone et al., 1991; Liu et al., 2011).

4.1.1 iv Simulation of the sitting interface

Sweating was simulated using a sweating cushion indenter which releases water vapour when a mass is loaded to mimic sitting (Ferguson-Pell, 2009). Metal oxide semiconductor sensors (Sensirion, 2010) were attached to the cushion in sitting location such as the thighs, ischial tuberosities and perineal area. The cushions were then loaded and the sensors measured the water vapour dissipation characteristics of the leaks at the sitting locations (Ferguson-Pell, 2009). The results showed that the perineal area was the warmest followed by IT regions. The sensor accuracy was reported to be ± 0.3 ˚C at 25 ˚C and ± 1.8 %RH at (0 – 100 % RH) and the testing environment was 21 ± 0.5 ˚C and 50 ± 5 %RH. These results indicate that, an ideal cushion should provide a surface temperature 3 ˚C less than body core temperature (37 °C) and a generally lower relative humidity level preferable around 40 %RH in order to maintain an appropriate microclimate between skin and cushion. If below 34 ˚C the cushions tested were considered high heat dissipaters. If above 36˚C, they were considered low heat dissipaters. Consequently below 40 %RH the cushions are high moisture dissipaters and above 60 %RH they are low. Simulation experiments are good for determining the characteristics of seat cushions although using human subjects provide a realistic measure of the values found (Ferguson-Pell, 2009) such as the studies in Table 4.1.

Table 4.1. Measurement of human participants in sitting

Authors	Sensor location	Clothes	Description	Sitting duration
Rithalia and Stockton (2007)	2 humidity and temperature sensors placed in the core of the cushion seat and the back cushion.	Not controlled	N = 5 (1 male, 4 female); Age: 43-84yrs; Sat on Four commercially available static pressure-reducing wheelchair cushions at home	10-16 hours a day for 7 days
Cengiz and Babalik (2007)	8 temperature sensors on body at the skin-clothing interface and 2 humidity sensors at the centre of the torso, front and back.	White shirt and white trousers provided	N = 10 (7 males, 3 females); Age: 31.8 ± 2.2 yrs; BMI=22.95 ± 4.1 kg/m2; Sat on a car seat with 3 covers: Velvet, jacquard and micro fibre. Room environment: 25 °C.	1 hour
McCarthy et al., (2009)	5 paired temperature and humidity sensors under the thighs, ischial tuberosities and the coccygeal region.	Jeans	N = 10 subjects (5 males and 5 females); Age: 19 - 41 yrs; BMI range 18.67 – 27.33 kgm^3; Sat on foam cushion; Room environment: 22± 0.2ºC and 30.1 ±0.5% RH.	1 hours
Liu et al (2011),	3 temperature sensors embedded in seat at locations: thighs and coccygeal region	Cotton trousers	N = 11 (6 males and 5 females); Age: 21 - 40 yrs; BMI range: 19.3 – 26.4 kgm^3; Sat on 3 seats foam, gel mould and wood; Room condition: 21.1 °C to 21.2 °C and 50%RH.	20 minutes
Posana-Morena et al., (2011)	Temperature sensors placed at sacrum, right and left scapula, right and left elbow, and right and left calcaneus	Not specified	N = 31 (14 males and 17 females); Age: 19- 29 years; Sat on same foam cushion with three surfaces: No cover, cotton and plastic; Room environment: 22 °C - 25 °C	Not specified
Vlaovic, Domljan and Grbac (2012).	Six 2-in-1 temperature and humidity sensor probes in the core of seat cushion: gluteus areas, thighs, on and in the seat surface, the centre of the seat surface (between the lower extremities) and behind the backrest	cotton underwear and light linen or cotton clothing	N = 6 (3 males, 3 females) ; Age: 35 ± 4.3 years; BMI range: 23.9 – 2.4 kgm^3; Sat on 5 office chair surfaces consisting of foams of varying densities; Room environment: 23.94 °C and relative humidity of 46.43 %	90 minutes

Key: The sitting studies carried out to detect humidity and temperature in human participants from literature.

4.1.1 v Biological variables important for measuring the seat microclimate.

Difference in sexes seem to exist in biomechanical studies where specific variations have been shown (Dunk and Callaghan, 2005; Ford et al., 2010). In terms of sex differences of skeletons it is accepted that the pelvic girdle is the most important part for sex determination. Generally male pelvic bones are larger and heavier than females and features of the female pelvis are influenced by sex hormones for the purpose of reproduction (Davivongs, 2005). Thermal comfort studies that observe temperature difference between sexes seem to yield small differences (McIntyre, 1980; De dear and Fountain, 1994; Lan et al., 2008). For equal sweat rates by males and females (per unit of body surface area), the skin temperature of females were 1 °C higher than men. This difference in sweat production between male and female has been reportedly due to increased cardiovascular disturbances with age (Shoenfeld et al., 1978).

The next section describes the methodology and studies carried out on human subjects to determine the reliability of sensors in a more realistic life-like situation. The characteristics of sensors found this in this chapter may be used to understand the limitations of the humidity sensors and from this, determine the feasibility of using them to monitor seated residents with dementia in the care home setting.

4.2 Methodology

Healthy participants volunteered to sit on seat surfaces so that humidity at the interface could be measured. This study comprised a series of sitting experiments using the two methodologies described in this chapter: (i) and (ii). Both studies (i) and (ii) incorporated descriptive statistics to analyse data. Studies (ia) and (ib) used inferential analysis, and this is described on Table 4.3

i: A kinematic study of prolonged sitting durations

a) **The relationship data between opposing anatomies of individual sexes**
b) **Relationship between the mean thighs and mean coccyx region: on three surfaces.**

ii: A kinematic comparison between sit and stand patterns

This research took place at the Faculty of Health, Sport and Science at the University of South Wales, Pontypridd between March and April 2012. The participants gave their written informed consent prior to participating in this experiment (Appendix 3a). The study was given ethical approval by the school of Applied Sciences Ethics Committee at the University of South Wales (Appendix 3b). Subject selection was based on healthy volunteers between 18 to 35 years of age. Subjects were encouraged to wear jeans so other materials were not influenced (McCarthy et al., 2009). Volunteers were asked to sit for a total of 50 minutes on sensors embedded in a seat cushion (cut out recesses to accommodate embedding of sensors: 30 mm x 40 mm x 20mm) in three conditions: with a cover, without a cover, and without a cover with sensors encapsulated in bags (Figure 4.2). The cover and bag material were both made from the same material (Invacare deep solutions cover: 0.4 mm thickness also made into bags with dimensions: 25 mm by 35 mm). Figure 4.2c shows the sensors (Honeywell HIH4000-004 and LM35) embedded in the cushion (400 mm x 400 mm x 120 mm) which when measured on the author, it translated to under the coccygeal region and the upper thigh region (Figure 4.3). The Invacare contoured cushion is moulded with a three dimensional seat surface created around the thighs and buttock area and this is believed to improve sitting stability (Cooper, 1998; Ham, Aldersea and Porter, 2004). These contoured features encourage the person to be seated in the same position each time, and based on this, the sensor locations were believed to be suitable to reliably measure the coccygeal and thigh regions across the different participants. Seat cushions were placed on stacking chairs used by students during lectures (Tubular Furniture Limited, Llantrisant, UK; Cascioli et al., 2011). Experiments were carried out in a laboratory with a desk in front so that they would be occupied by personal study. The sitting tests took 4 weeks to complete and the average ambient environment (measured every day) during the study was 22 °C ± 0.3 °C and relative humidity of 47 ± 1.2 %RH.

Figure 4.2: Sensors and seat set-up

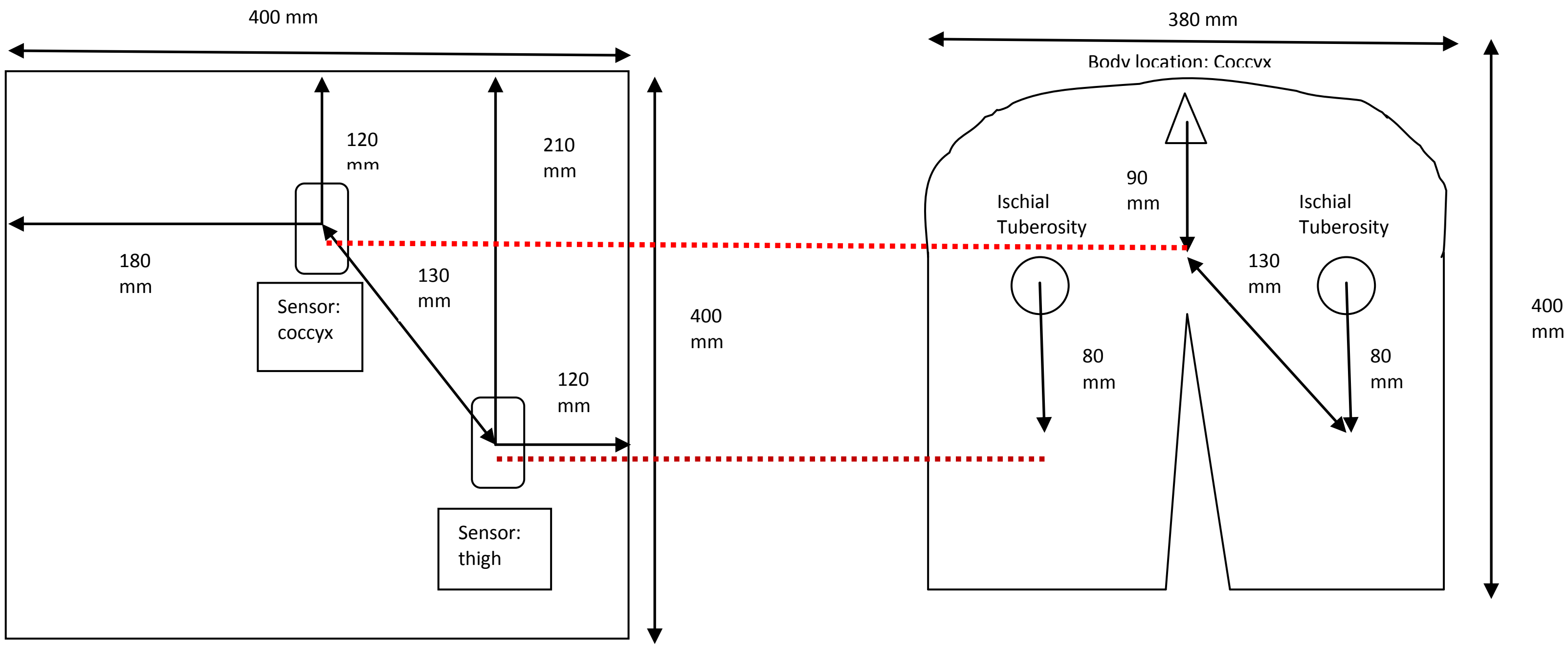
a) Sensors no cover

b) Sensors with a cover

c) Humidity sensors in bags

Key: Six pairs of temperature and humidity sensors splits into three pairs and embedded into two identical seats (left seat and right seat. The sensors measured the participants with a) no cover; b) with a cover; and c) when in bags. The sensors were embedded at three locations under the thighs and in the coccygeal region. The two humidity sensors under the thighs showed identical results so for analysis; the output of the left thigh was used.

Figure 4.3: Location of seat positions translated from the human body in sitting.



Key: The left diagram displays the seat cushion with the two sensors (one located under the left thigh and the other coccyx) including : Their proximal measurements. The diagram on the right shows the seated area of the human body, when mirrored onto the seat, the area below the coccyx and ischial tuberosities are where the sensors have been embedded.

4.2 i Sample participants

In this study a total of 12 participants, (6 males and 6 females) ranging in age from 19 to 34 years (Appendix 3c) served as subjects from a group (N = 108) of first year students on the Chiropractic degree course which was approved by the Faculty of Health, Sport and Science ethics committee. One female subject left the experiments due to lack of commitment to the study. The eleven participants had the following characteristics (mean and standard deviations in parentheses): age (23.1 ± 5 years); height (1.74 ± 0.1 m); mass (76.5 ± 14.3 kg) and BMI (24.9 ± 2.9 $kg{\cdot}m^{-2}$). The height and mass were recorded once for each subject before the experiments. According to the sexes the characteristics of the females and males were different (Females: age (22.6 ± 4.3 years); height (1.68 ± 0.1 m); mass (67.4 ± 8.2 kg) and BMI (23.9 ± 3.0 $kg{\cdot}m^{-2}$; Males: age (23.5 ± 5.9 years); height (1.8 ± 0.1 m); mass (84.2 ± 14.2 kg) and BMI (25.8 ± 2.8 $kg{\cdot}m^{-2}$)). The males were generally taller and heavier.

4.2 ii Experimental Process

Two tests were carried out to investigate the humidity at the sitting interface between subjects and a cushion. The first involved eleven participants (males and females) who sat on the three seat conditions for 50 minutes each (2.5 hours per person and a total of 27.5 hours). The second involved, two participants (from the eleven) who carried out a sit and stand test six times on each seat condition (15 hours per person). Although 50 minutes were measured, only 40 minutes of the data was found to be of most value. These two experiments were selected from original tests which included the 11 participants seated on four surfaces (Table 4.2). Additional testing was carried out where all participants were required to be seated on an extra seat condition: sensors with bags with an additional seat cover. This test was disregarded because the sensors were unable to measure through that condition. The sensors measured one sample a second, so for 50 minutes there were 3000 data points collected.

Study outline

The aims, objectives and research questions for this chapter can be seen in Table 1.1 in Chapter 1. To reinforce the findings of the test, ‘a kinematic study of prolonged sitting durations’ the following two statistical tests were carried out: Table 4.3 provides the study background, aims, null hypothesis and statistical analysis for these additional tests.

Table 4.2: Original tests carried out

Participants	Seat conditions	Duration (Hours)
N=11 (seated for 50 minutes on each condition)	Four	Per person: 3.3; Total: 36.3 Total data points: 130, 680
N=11 (sit and stand for 50 minutes on each seat condition)	Four	Per person: 3.3; Total: 36.3 Total data points: 130, 680
N=2 (seated 6 times on each seat condition that ran for 50 minutes)	Four	Per person: 20; Total: 40 Total data points: 144, 000
N=2 (sit and stand (x6) on each seat surface conditions that ran for 50 minutes.	Four	Per person: 20; Total: 40 Total data points: 144, 000
Total time spent and number of data points used for analysis		152.6 hours and 549, 360 points

Key: This table shows the duration of sitting

Table 4.3Prolonged sitting tests (A kinematic study of prolonged sitting durations), analysed used inferential statistics.

Title	The relationship data between opposing anatomies of male vs female
Study	To investigate the difference between the thigh and coccyx for male and female a statistical test was carried out involving data from sitting on embedded sensors with no cover.
Aim	The aim was to find out if there was a significant difference between the sensors measuring the thighs and the coccyx for male vs female.
H_0	The null hypothesis took the following form: H_0: there is no difference between the thigh and coccygeal region for either the males of females.
Statistical analysis	The samples were normally distributed which fulfil the parametric tests assumptions. Therefore, a paired samples t-test (or a repeated measures test) was carried out because the two locati thighs and coccyx, were compared in turn for: females and males. Each sex was assessed on the basis of continuous measures from thighs and then coccyx. SPSS PASW 18 was used to investigate. The average data from the eleven participants were used when seated on the sensors embedded in the foam seat without a seat cover
Relationship to Chapter 3	This study relates to Study 4 in Chapter 3: 'Material comparison for encapsulating sensors' for which the H_0: was rejected because there was no significant difference found ($p > 0.05$) betw sensors measuring without a cover and those measuring through a variety of materials .. The research question was : Is there a suitable material that can protect sensors and still allow them to n reliable measurements? Therefore, the answer to this is yes, which was also demonstrated through the sitting tests (chapter 4).
Title	Relationship between the mean thighs and coccyx region across three surfaces.
Study	To investigate the relationship between the mean humidity at the thighs and coccygeal regions across the group of participants (n = 11), when seated on a variety of seat surfaces.
Aim	The aim was to find out if there is a difference between the humidity recordings from under the thigh and coccyx at 8 time points (across the duration of experiment) for 3 different sitting surfa This was carried out as follows: sampling at 20 Epoch points comprising 8 time points (the start [time 0] and then at 1, 5, 10, 20, 30, 40 and 50 minutes). Data from each of these points was avera to represent the sensors output during that time. After these calculations were made for each individual who had sat on the seat surfaces for 50 minutes each,, the data from the left and right th were also averaged for each individual, revealing they had very similar results.
H_0	The null hypothesis took the following form: there is no difference between the thigh and coccyx for the three surfaces across the sitting duration for all participants.
Statistical analysis	A two way independent ANOVA test was carried out to test the difference between coccyx and thighs for sensors with no cover (NC), sensors with a cover (C) and sensors in bags (B). The two independent variables used in the study were the anatomical location and the surface condition, and the one dependant variable was the humidity. The advantage of using a two way ANOVA is that it can be used to test the main effect of each independent variable, and explore any interaction effects which will indicate the influence of one independent variable on the dependant variable.
Relationship to Chapter 3	This study related to Study 5 reported in Chapter 3: 'Sensitivity of sensors on water detection' for which the H_0: 2) 'There is no difference when water drops are introduced' was rejected because no significant difference found ($p > 0.05$). The research question 'Are the sensors able to detect moisture at different proximities?' was answered positively, however this was also found w differences in humidity were detected between subjects in sitting.

Key: Studies carried out for prolonged sitting tests. Abbreviation H_0 refers to Null hypotheses. This study related some of the hypothesis from Chapter 3 in order to understand the rationale underpinning chapter 4.

4.3 Results

4.3.1. A kinematic study of prolonged sitting durations

This study investigated the difference in humidity measurement at the thigh and coccygeal region for 11 participants when seated on sensors with no cover. For all participants combined there was a difference found between the coccygeal region and the thighs when sat on the seat surface with no cover (Figure 4.4): explained as follows. In relation to the eleven participants seated on three surface conditions, the sensors consistently measured higher humidity's in the coccygeal region irrespective of seat surface (Tables 4.4 and 4.5). Males generally had higher humidity's than females when seated on all three surfaces. For both sexes, the coccyx was still higher than the thighs. In terms of temperatures, the males had very slightly higher temperatures under the coccyx, However females had higher thigh temperatures (Coccyx: males (32.6 ± 1.8 °C; range: 30.4 - 35.6 °C) and females (32.1 ± 0.9 °C; range: 30.9 - 33.4 °C); Thighs: males (27.9 ± 1.2 °C; range: 31.9 - 35.0 °C) and females (32.4 ± 1.2 °C; (30.8 - 33.8 °C).

4.3.1.1 The relationship data between opposing anatomies of individual sexes

The inferential statistical analysis yielded the following results (Table 4.6). The interpretations will be carried out on the males and females in turn. In the male group of participants there was a statistically significant decrease in the thigh score, coccyx (55.7 ± 1.7 %RH) and thighs (51.1 ±1.7 %RH), $t(5) = -4.926$, $p > 0.004$ (two tailed) (Table 4.6). The mean decrease was from coccyx to thighs was -4.6 (95 % confidence interval). The eta squared statistic (0.65 %) indicated a large effect. In the female group there was also a statistically significant decrease in the thigh score, coccyx (50.8 ± 1.0 %RH) and thighs (46.1 ± 1.7 %RH), $t(5) = -3.037$, $p > 0.029$ (two tailed). The mean decrease was from coccyx to thighs was 4.7 (95 % confidence interval). The eta squared statistic (0.83 %) indicated a large effect.

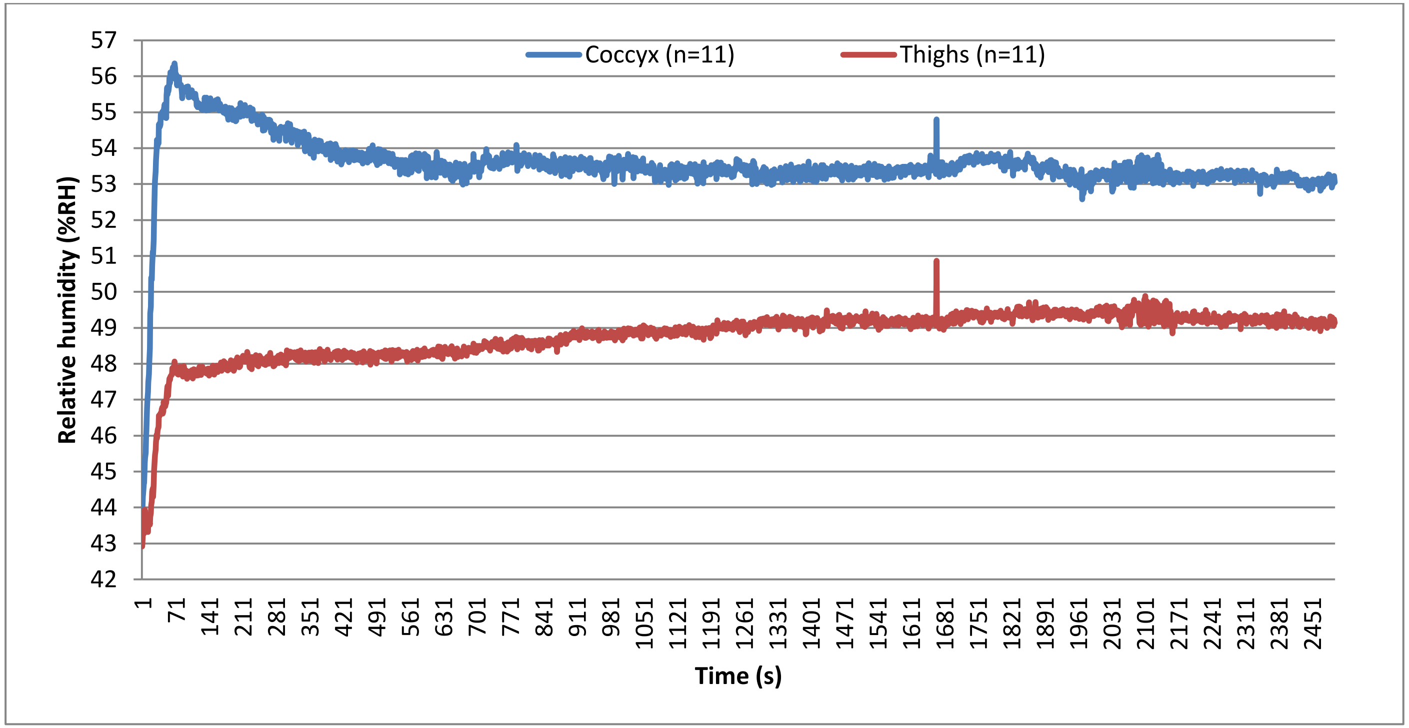
4.3.1.2 Relationship between the mean thighs and coccyx region on three surfaces.

The results for this test are presented in table 4.7 and interpreted as follows. The seat surfaces were presented in three conditions:

- Group 1: Sensors with no cover (NC);
- Group 2: Sensors with a cover (C);
- Group 3: Sensors in bags (B).

The results on table 4.7 show the two-way independent analysis of variance, conducted to explore the impact of location of sensors and the three sitting surfaces on levels of humidity. If the Levene's test significance is $p < 0.05$ (less than 0.05), this suggests that the variance across the group is not equal. At times 1 minute ($p = 0.01$) and 40 minutes ($p = 0.000$), the p value was less than 0.05 ($p < 0.05$), therefore both results are significant suggesting that the variance are unequal and there was no difference between all surfaces. For the rest of the times, the p value was higher than 0.05 ($p > 0.05$), which is not a significant value so therefore they do not violate the homogeneity of variances assumption. In other words there was no difference found. The location gave no significant effect throughout the experiment ($p > 0.05$); therefore there were no changes in the humidity scores between the thigh and coccyx. There was a statistically significant main effect for the sitting surface between times 10 minutes and 40 minutes, which means that there was a difference in humidity scores for sensors with a cover, no cover and in bags. At all other times, the surface gave no significant results (no difference in scores). However the partial eta effect size for the sitting surfaces was large, between time 1 and 40minutes. According to Cohen's D, this means that the effect may be noticeable through visual observation of results. A medium eta score was found only at the 'start' and at '50' minutes. This may indicate that these two time points may be not as noticeable as between times 1 and 40 minutes. For the locations thigh and coccyx, the eta size was found to be small in all times apart from times '10' and '40' minutes where they were medium. Post hoc comparisons using Tukey HSD test indicated that the highest means were measured by the sensors that were exposed with no cover. At the start and 1 minute into the test, the sensors in bags measured higher than the sensors with cover (no bags). This happens again at 10 minutes. However at 5 minutes, and from 20 minutes onwards, this changes and it is the sensors in bags that measured the lowest mean although the sensors (not in bags) under a cover, measured higher.

Figure 4.4: Humidity measured under the thigh and coccygeal region



Key: Graph representing the humidity for n=11 at the coccyx and thigh region when seated on sensors with no cover. (n = number or subjects). Coccyx: The starting humidity of 43.7 %RH increased rapidly (curvilinear shape), and peaked at 56.4 %RH after 69 seconds. It then decreased rapidly (curvilinear shape) to 53.2 %RH at 10 minutes (600 seconds) after which it stabilises at 53 %RH. Thighs: The starting humidity for the thighs is lower than the coccyx at 42.9 %RH although increases steeply to 47.8 %RH after 69 seconds. It then remains stable with a minimal increase (between 47.8 and 48.4 %RH: 0.6 %RH increase) for 10 minutes (600 seconds). The humidity then increases at a faster rate although gradually (between 48.3 %RH and 49.2 %RH: 0.9 %RH increase) until 35 minutes (2100 seconds) after which it remains stable at 49 %RH.

Table 4.4: Humidity measurements for males and females.

Participants/Sex		No cover		Cover		Bags	
		Thighs	Coccyx	Thighs	Coccyx	Thighs	Coccyx
Females	1	**46.9 ± 1.9** *(36.9 to 48.6)*	**50.9 ± 1.9** *(36.2 to 53.6)*	**39.9 ± 2.4** *(33.9 - 45.8)*	**47.6 ± 6.4** *(35.5 - 56.4)*	**38.6 ± 0.5** *(37.1 - 40.4)*	**43.9 ± 0.8** *(39.7 - 45.7)*
	2	**49.3 ± 2.5** *(37.7 - 51.1)*	**57.1 ± 0.8** *(46.4 - 58.8)*	**49.8 ± 5.3** *(36.7 - 60.3)*	**41.9 ± 0.7** *(38.4 - 43.2)*	**41.2 ± 1.1** *(38.3 - 43.5)*	**44.1 ± 0.6** *(40.7 - 46.1)*
	3	**49.7 ± 2.5** *(36.5 - 51.7)*	**48.9 ± 3.1** *(35.0 - 51.7)*	**38.7 ± 2.6** *(32.4 - 43.4)*	**43.2 ± 3.9** *(34.7 - 49.3)*	**42.8 ± 1.6** *(37.5 - 45.4)*	**49.9 ± 1.5** *(42.9 - 51.6)*
	4	**34.7 ± 1.63** *(29.2 - 37.1)*	**37.5 ± 2.7** *(27.2 - 39.7)*	**31.9 ± 0.8** *(30.7 - 35.0)*	**36.5 ± 1.9** *(32.5 - 40.3)*	**32.4 ± 1.1** *(29.5 - 35.2)*	**30.2 ± 0.9** *(28.0 - 32.6)*
	5	**44.1 ± 1.4** *(34.6 - 45.8)*	**51.3 ± 0.9** *(42.3 - 53.0)*	**48.0 ± 4.6** *(37.9 - 60.2)*	**32.1 ± 21.2** *(28 -43.6)*	**38.9 ± 1.7** *(34.5 - 42.6)*	**45.7 ± 1.3** *(39.7 - 46.7)*
	6	**58.1 ± 5.1** *(34.9 - 70.8)*	**52.5 ± 1.9** *(33.6 - 55.4)*	**42.1 ± 2.8** *(35.6 - 47.9)*	**46.4 ± 4.7** *(36.5 - 54.9)*	**36.7 ± 0.4** *(34.9 - 37.7)*	**42.2 ± 1.7** *(37.9 - 45.3)*
Males	7	**36.6 ± 2.5** *(26.3 - 57.0)*	**40.2 ± 2.1** *(27.9 - 59.5)*	**28.8 ± 0.6** *(28.0 - 30.6)*	**33.8 ± 2.3** *(29.8 - 41.3)*	**36.3 ± 6.7** *(30.8 - 80.0)*	**44.3 ± 2.9** *(35.1 - 48.9)*
	8	**46.2 ± 1.1** *(36.4 - 47.6)*	**50.2 ± 1.6** *(46.5 - 52.5)*	**47.0 ± 4.6** *(37.4 - 57.3)*	**59.5 ± 6.2** *(43.0 -76.2)*	**47.2 ± 2.7** *(38.9 - 55.8)*	**45.3 ± 1.0** *(41.9 - 47.9)*
	9	**47.7 ± 3.4** *(36.0 - 59.7)*	**53.3 ±** 4.4 *(38.3 - 63.9)*	**40.5 ± 2.7** *(33.2 - 47.7)*	**48.1 ± 5.1** *(34.5 - 56.4)*	**57.7 ± 4.2** *(36.6 - 60.9)*	**66.7 ± 5.6** *(40.2 - 70.6)*
	10	**54.2 ± 1.7** *(37.9 - 56.3)*	**65.5 ± 3.5** *(41.5 - 72.8)*	**49.8 ± 5.3** *(37.5 - 61.8)*	**42.6 ± 1.3** *(40.1 - 46.7)*	**36.8 ± 1.0** *(33.4 - 38.8)*	**55.6 ± 5.2** *(33.9 - 61.9)*
	11	**48.9 ± 2.1** *(31.6 - 52.3)*	**51.7 ± 1.9** *(31.7 - 56.1)*	**47.6 ± 2.9** *(36.9 - 55.4)*	**48.9 ± 3.7** *(37.2 - 57.2)*	**37.9 ± 1.6** *(33.6 - 41.3)*	**48.0 ± 2.4** *(36.7 - 51.9)*

Key: Sensors measuring under the thighs and coccyx for individual participants seated on three seat conditions.

Table 4.5: Mean humidity measurements for males and females.

	No cover		Cover		Bags	
	Thighs	**Coccyx**	**Thighs**	**Coccyx**	**Thighs**	**Coccyx**
Mean of 11	**48.6 ± 1.0**	**53.2 ± 1.5**	**39.4 ± 2.1**	**46.5 ± 2.5**	**40.2 ± 0.9**	**47.2 ± 1.8**
range	*42.9 - 50.9*	*43.8 - 56.4*	*32.9 - 42.9*	*39.9 - 52.3*	*36.4 - 41.7*	*38.8 - 49.1*
Mean of 6 females	**46.1 ± 1.7**	**50.8 ± 1.0**	**37.8 ± 3.5**	**45.3 ± 3.2**	**38.1 ± 0.5**	**43.1 ± 0.9**
range	*36.4 - 47.3*	*38.6 - 51.9*	*27.6 - 41.3*	*37.3 - 51.2*	*36.6 - 39.6*	*38.9 - 44.2*
Mean of 6 males	**51.1 ± 1.7**	**55.7 ± 2.5**	**41.3 ± 1.2**	**47.9 ± 2.4**	**42.6 ± 1.5**	**52.2 ± 2.9**
range	*40.9 - 55.2*	*40.7 - 61.9*	*37.7 - 45.1*	*40.6 -54.6*	*35.9 - 45.4*	*38.3 - 55.9*

Key: The mean total humidity outputs for thighs and coccyx under all participants and when broken down into males and females.

Table 4.6: Results of the paired samples test

Gender		Mean	SEM*	SD*	t-test	p-value
Males	Thigh	51.1	5.9	1.7	6.212	0.004
	Coccyx	55.7	3.9	2.5		
Females	Thigh	46.1	17.9	1.7	3.037	0.029
	Coccyx	50.8	5.8	1.0		

Key: *SEM-standard errors of mean; SD-standard deviation

Table 4.7. Results from the Two way Anova test.

Two way anova tests	Times (minutes)							
	Start	**1**	**5**	**10**	**20**	**30**	**40**	**50**
Levernes test significance	0.072	0.01	0.202	0.345	0.238	0.519	0.000	0.159
Interaction effect	F(2,53)=0.857, p=0.430	F(2,53)=1.79, p=0.178	F(2,53)=1.3, p=0.281	F(2,53)=2.31, p=0.098	F(2,53)=1.260, p=0.292	F(2,53)=1.97, p=0.149	F(2,53)=1.740, p=0.185	F(2,53)=1.77, p=0.181
Main effect	Location= 0.72 Surface=0.131	Location= 0.333 Surface=0.000	Location= 0.796 Surface=0.08	Location= 0.073 Surface=0.001	Location= 0.753 Surface=0.030	Location= 0.114 Surface=0.018	Location= 0.163 Surface=0.025	Location= 0.356 Surface=0.435
Partial Eta squared (Eta size)	Surface = 0.074 (M); Location =0.002 (S)	Surface =0.328(L); Location = 0.018(S)	Surface =0.168(L); Location = 0.001(S)	Surface =0.243(L); Location = 0.059(M)	Surface =0.124(L);Location = 0.002(S)	Surface =0.141(L); Location = 0.047(M)	Surface =0.130(L); Location = 0.036(S)	Surface =0.031(M); Location =0.016 (S)
Post hoc*	p>0.05 so all surfaces did not differ	Differ =NC&C, NC&B No Diff=B&C	Differ=NC&B No Difference= NC&C, C&B	Differ=NC&C, NC&B No Difference=C&B	Differ=NC&B No Difference=NC&C, C&B	Differ=NC&B No Difference=NC&C, C&B	Differ=NC&B No Difference=NC&C, C&B	No difference=NC&C,NC&B,C&B
Tukey means (performance)	Highest= NC Middle=B Lowest=C	Highest= NC Middle=B Lowest=C	Highest= NC Middle=C Lowest=B	Highest= NC Middle=B Lowest=C	Highest= NC Middle=C Lowest=B	Highest= NC Middle=C Lowest=B	Highest= NC Middle=C Lowest=B	Highest= NC Middle=C Lowest=B

Key: *NC= Sensors with no cover; C=Sensors with a cover; B=Sensors is bags); L=Large, M=Medium, S=Small); Diff/Differ = Difference

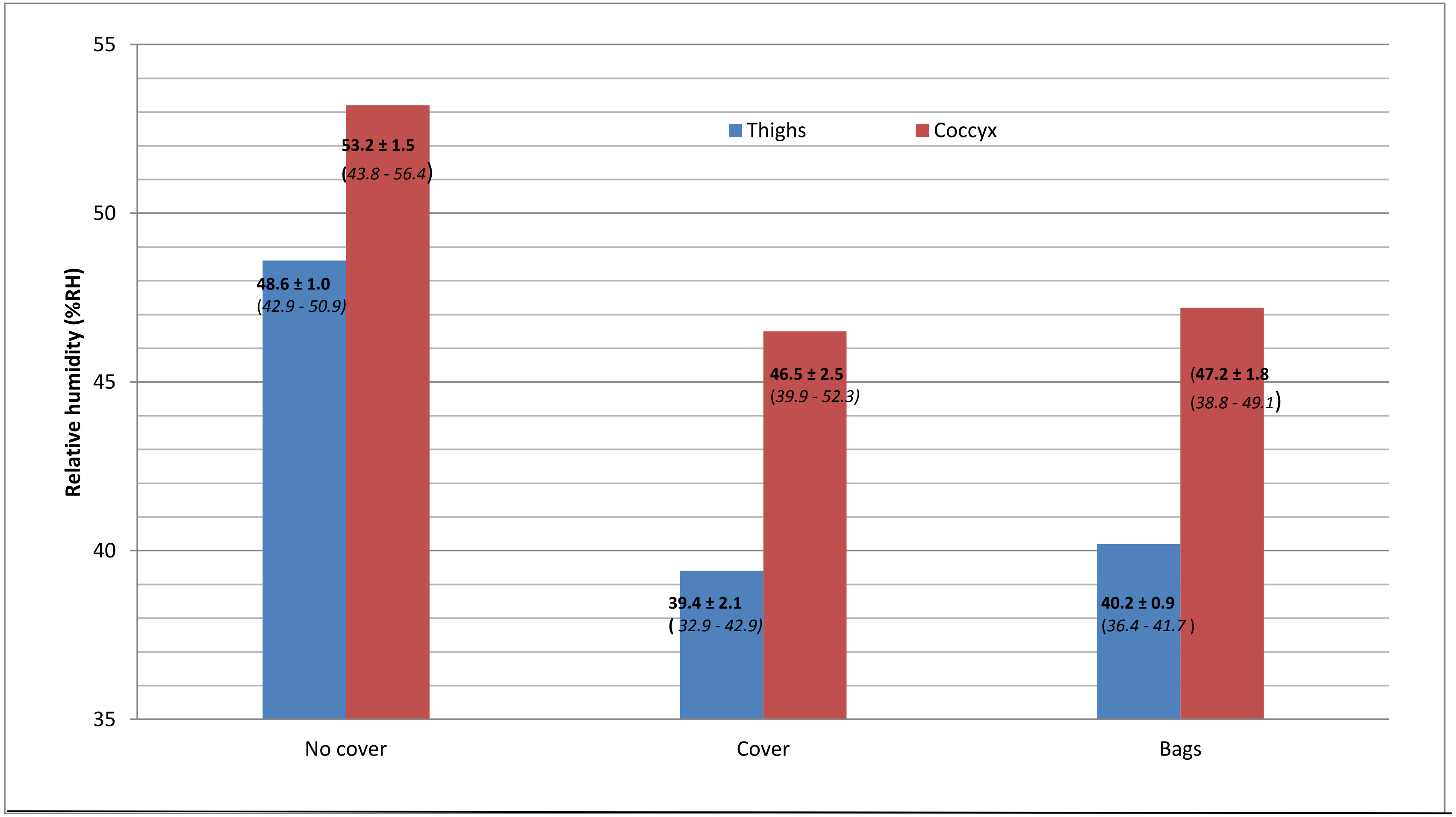
4.3.1.3 Summary of results

The interaction effect between the sensor location (thigh and coccyx) and the sitting surface groups was not statistically significant ($p > 0.05$) throughout all the times of the experiment. This means that there was no difference in the effect of the sitting surface condition on humidity for the thighs and coccyx. However through descriptive analysis (Figure 4.5), the coccyx was slightly higher (maximum values) than the thighs in general on all three surfaces:

Thighs: No Cover (**48.6 ± 1.0** %RH; range: *42.9 - 50.9* %RH)
Cover (**39.4 ± 2.1** %RH; range: *32.9 - 42.9* %RH)
Bags (**40.2 ± 0.9**%RH; range: *36.4 - 41.7* %RH)

Coccygeal: No Cover (**53.2 ± 1.5**%RH; range: *43.8 - 56.4*%RH)
Cover (**46.5 ± 2.5** %RH; range: *39.9 - 52.3*%RH)
Bags (**47.2 ± 1.8**%RH; range: *38.8 - 49.1* %RH)

Figure 4.5: Average relative humidity of the thighs and coccygeal regions on different surfaces



Key: Average relative humidity of the thighs and coccygeal regions on different surfaces with the minimum and maximum ranges in the parentheses.

4.3.2 A kinematic comparison between sit and stand patterns.

4.3.2.1 Introduction

Two subjects who were healthy young individuals were each required to be seated on a foam cushion (Invacare Contour Plus) embedded with three humidity sensors (HIH 4000-04) and three temperature sensors (LM35) and their patterns of sitting and standing were studied under the thighs and coccygeal region (Olufsen, Tran and Ottesen, 2004; Olufsen et al., 2005). Each subject sat six times on three seat conditions: no cover, with a cover and in bags. The choice of using minimal participants with high frequency testing allowed the average value to be more consistent. The two individuals were a male [J = age (27 years) height (1.69 m); mass (63 kg); BMI (22.1kg·m^{-2})] and a female [L = age (30 years); height (1.73 m); mass (67 kg); BMI (22.4 kgm^{-2})]. This study investigates the difference between the two sexes.

4.3.2.2 Methodology

At the very beginning of the 50 minute experiment each subject was asked to stand in front of the seat for one minute whilst the sensors captured a reading with no interruptions. After this the subjects sat on the cushion for 10 minutes. Once the 10 minutes were over, they were prompted to stand up for as further 10 minutes in front of the seat without resting on anything (Figure 4.6). Subjects repeated this sit and stand pattern for three cycles within the 50 minutes duration.

4.3.2.3 Data analysis

The measurements of the left and right thighs were very similar for all subjects and so the average of the thigh measurement was used. Therefore two measurements, the coccyx and the averaged thigh value were examined in this study.

The humidity sensor output for the sit and stand cycles of the thighs and coccygeal regions are shown in figure 4.7 (an example of the data pattern for one subject on a voltage scale). The following description explains the meaning of the labels surrounding figure 4.7.

- **Start:** The sensors measured one minute with no interruptions at the beginning of the 50 minutes experiment.
- **Sit data**: Also known as 'Peak 1, 2 or 3' is the rise in humidity while the subject sits as measured by the sensors lasting 10 minutes. The mean of the output is calculated between the indicated regions.

- **Stand data**: Also known as 'Trough 1, 2 or 3 is the fall in humidity while the subject sits as measured by the sensors lasting 10 minutes. The mean of the output is calculated between the indicated regions.
- **Absolute Change:** The two stars on the beginning and end of peak 3 indicate the values used to measure the absolute change in humidity measurement. This involves subtracting the humidity values between these two points. From the results of the subtraction a negative outcome indicates a fall in humidity and a positive outcome indicates a rise in humidity. The absolute change is calculated for all peaks and troughs (Table 4.9)
- **Percentage change:** This is not shown in the figure 4.7, although it is calculated and displayed in table 4.8. The percentage change is found by dividing the absolute change by the humidity at the beginning of the peak or trough being measured. Similar to the absolute change outcome, a negative and positive outcome indicate a fall and rise in humidity respectively.

The humidity at 50 %RH and then at the maximum is in Table 4.8 and displayed in Figure 4.8.

4.3.3 Summary of results: Difference between the male and female participants.

The diagram on figure 4.7 shows average results of the males and females and the humidity measurements taken under the coccyx and thighs. In order to justify if there is a difference between the humidity outputs under the thighs and coccyx of male and female participant the following averages of sit and stand were computed:

Females

Thigh region mean of ***sit***: 29.3 ± 0.1 %RH (range: 29.3 - 29.4 %RH)

Coccygeal region mean of ***sit***: 29.9 ± 0.1 %RH (range: 29.8 - 29.9 %RH)

Thigh region mean of ***stand:*** 27.3 ± 0.3 %RH (26.9 - 27.5 %RH)

Coccygeal region mean of ***stand: 25.9*** ± 0.3 %RH (25.6 - 26.2 %RH)

Males

Thigh region mean of ***sit***: 35.1 ± 3.9 %RH (range: 30.5 - 37.4 %RH)

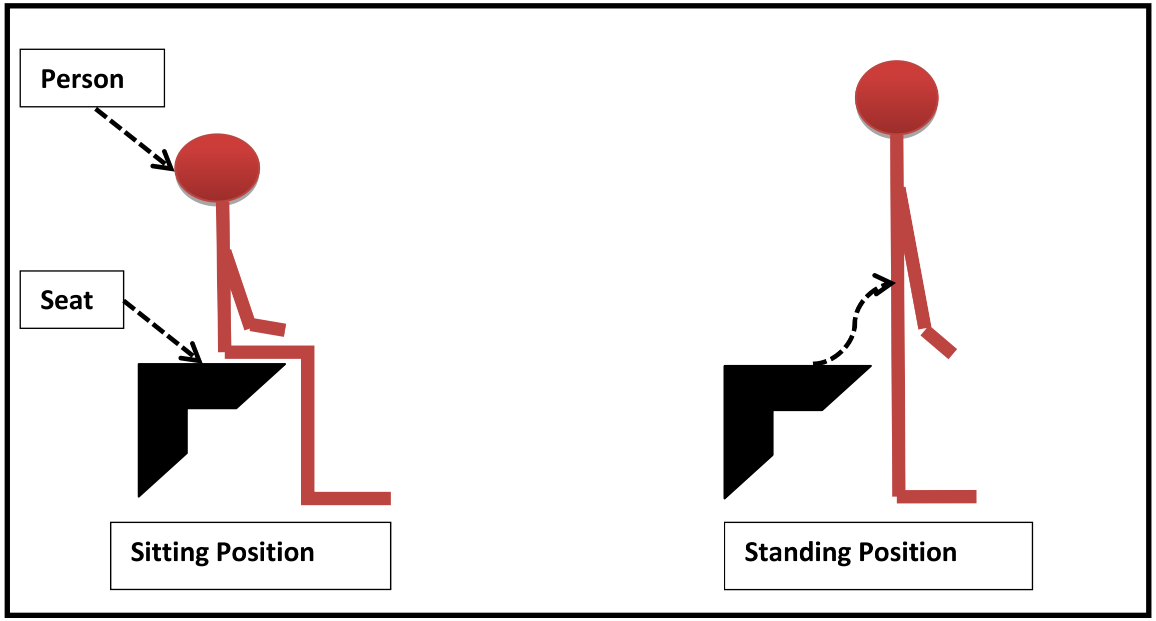
Coccygeal region mean of ***sit***: 40.9 ± 2.1 %RH (range: 38.6 - 42.6 %RH)

Thigh region mean of ***stand:*** 25.1 ± 0.2 %RH (25.0 - 25.3 %RH)

Coccygeal region mean of ***stand:*** 26.1 ± 0.3 %RH (25.8 - 26.3 %RH)

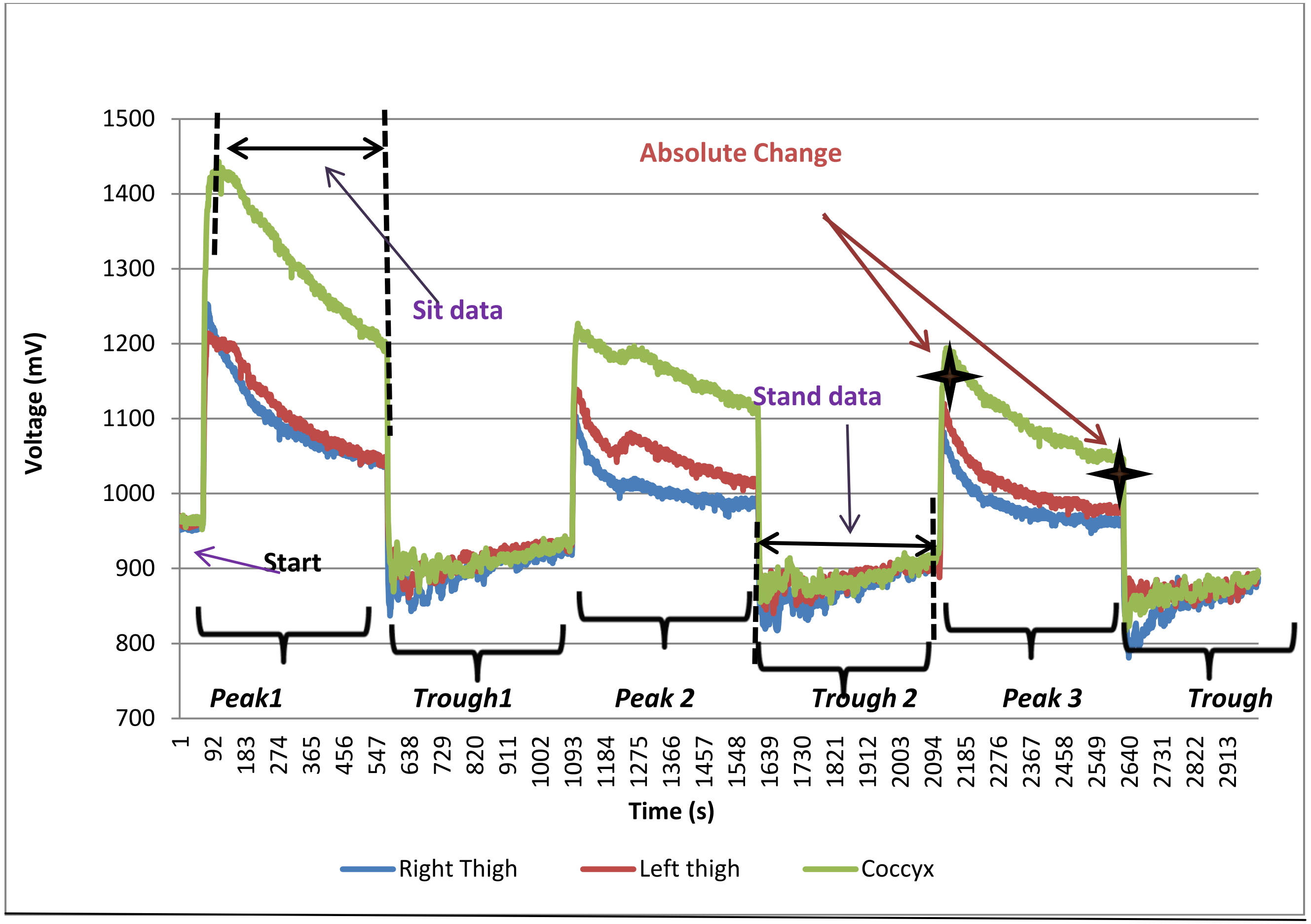
The mean humidity's of the coccyx is higher than the output humidity of the thighs. For both anatomical locations, the males have a higher output than the females (Figure 4.8).

Figure 4.6: Schematic diagram to show the activity of sit and stand in this study.



Key: Subjects repeated this sit and stand pattern for three cycles within the 50 minutes duration.

Figure 4.7: Humidity sensors: Subject 3 Sit and stand on sensors with no cover



Key: Original voltage output from humidity sensors in foam seat of subject 3 (Male). Example of how data was analysed.

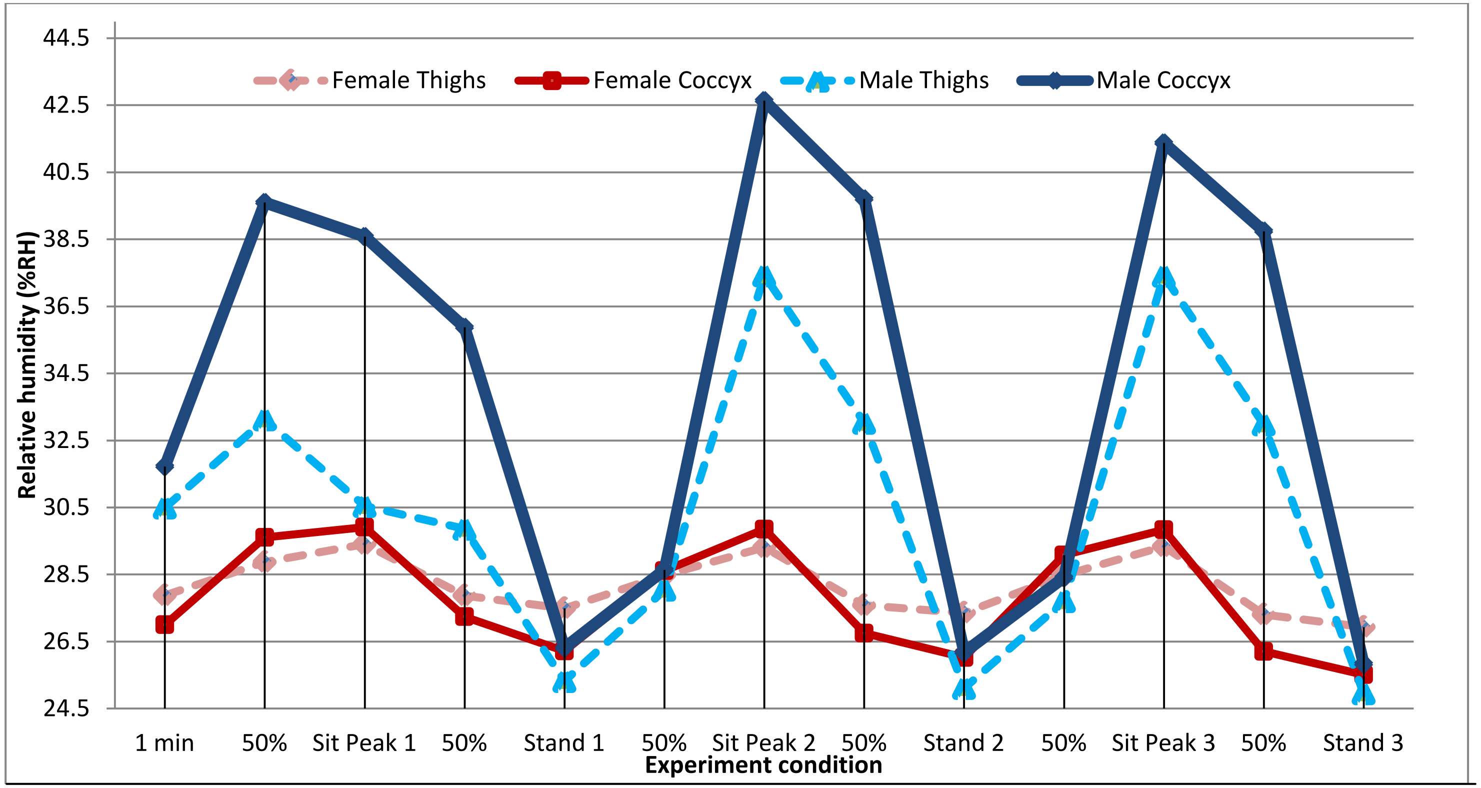
Table 4.8: Relative humidity at 50 % to the maximum value of sitting

	Relative humidity (%RH)												
Female	**1 min**	**50% to max**	**Sit Peak 1**	**50% to max**	**Stand 1**	**50% to max**	**Sit Peak 2**	**50% to max**	**Stand 2**	**50% to max**	**Sit Peak 3**	**50% to max**	**Stand 3**
Thighs	**27.9 ± 0.2**	**28.9 ± 0.1**	**29.4 ± 0.2**	**27.9 ± 0.1**	**27.5 ± 0.1**	**28.5 ± 0.1**	**29.3 ± 0.1**	**27.6 ± 0.1**	**27.4 ± 0.1**	**28.5 ± 0.1**	**29.3 ± 0.1**	**27.3 ± 0.1**	**26.9 ± 0.2**
range	(27.4 - 28.4)	(28.6 - 29.1)	(29.1 - 29.7)	(27.6 - 28.1)	(27.3 - 27.6)	(28.2 - 28.8)	(29.1 - 29.7)	(27.4 - 27.8)	(27.1 - 27.5)	(28.2 - 28.7)	(29.1 - 29.6)	(27.1 - 27.5)	(26.6 - 27.2)
Coccyx	**27.0 ± 0.3**	**29.6 ± 0.1**	**29.9 ± 0.2**	**27.2 ±0.1**	**26.2 ± 0.1**	**28.6 ± 0.1**	**29.9 ± 0.2**	**26.8 ± 0.1**	**26.0 ± 0.1**	**29.1 ± 0.1**	**29.8 ± 0.2**	**26.2 ± 0.1**	**25.6 ± 0.1**
range	(26.6 - 27.8)	(29.4 - 30.0)	(29.5 - 30.3)	(27.0 - 27.5)	25.9 - 26.4)	(28.3 - 28.9)	(29.6 - 30.1)	(26.6 - 26.9)	(25.8 - 26.2)	(28.8 - 29.3)	(29.5 - 30.2)	(26.0 - 26.5)	(25.3 - 25.7)
	Relative humidity (%RH)												
Male	**1 min**	**50%**	**Sit Peak 1**	**50%**	**Stand 1**	**50%**	**Sit Peak 2**	**50%**	**Stand 2**	**50%**	**Sit Peak 3**	**50%**	**Stand 3**
Thighs	**30.5 ± 2.9**	**33.1 ± 0.1**	**30.5 ± 0.2**	**29.9 ± 1.2**	**25.3 ± 0.2**	**28.0 ± 0.2**	**37.4 ± 0.6**	**33.0 ± 0.1**	**25.1 ± 0.2**	**27.7 ± 0.1**	**37.4 ± 0.4**	**33.0 ± 0.1**	**25.0 ± 0.2**
range	(27.0 - 37.6)	(33.0 - 33.4)	(30.2 - 30.9)	(28.0 - 30.9)	(25.0 - 25.7)	(27.8 - 28.4)	(36.5 - 38.4)	(32.8 - 33.4)	(24.5 - 25.6)	(27.5 - 27.9)	(36.6 - 38.2)	(32.7 - 33.2)	(24.7 - 25.4)
Coccyx	**31.7 ± 4.2**	**39.6 ± 0.1**	**38.6 ± 0.3**	**35.9 ± 3.6**	**26.3 ± 0.3**	**28.6 ± 0.2**	**42.6 ± 0.2**	**39.7 ± 0.1**	**26.2 ± 0.4**	**28.4 ± 0.2**	**41.4 ± 0.2**	**38.7 ± 0.1**	**25.8 ± 0.3**
range	(28.7 - 41.9)	(39.4 - 39.8)	(38.1 - 39.2)	(30.1 - 38.7)	(25.8 - 26.9)	(28.3 - 29.0)	(42.2 - 43.1)	(39.4 - 39.9)	(25.6 - 26.8)	(28.0 - 28.7)	(41.1 - 41.6)	(38.5 - 39.0)	(25.3 - 26.6)

Table 4.9: Absolute change and percentage changes for the sit and standing positions

Female Thighs	Absolute change (%RH)			Percentage change (%)		
	Sit 1	**Sit 2**	**Sit 3**	**Sit 1**	**Sit 2**	**Sit 3**
	1.3	2.2	2.2	4.6	8.1	8.1
	Stand 1	**Stand 2**	**Stand 3**	**Stand 1**	**Stand 2**	**Stand 3**
	2.4	2.2	2.4	8.1	7.5	8.1
Female Coccyx	**Sit 1**	**Sit 2**	**Sit 3**	**Sit 1**	**Sit 2**	**Sit 3**
	3.0	3.5	4.0	10.9	13.4	15.3
	Stand 1	**Stand 2**	**Stand 3**	**Stand 1**	**Stand 2**	**Stand 3**
	4.2	3.4	4.7	13.9	11.5	15.6
Male Thighs	**Sit 1**	**Sit 2**	**Sit 3**	**Sit 1**	**Sit 2**	**Sit 3**
	4.8	5.6	4.8	12.7	14.9	12.8
	Stand 1	**Stand 2**	**Stand 3**	**Stand 1**	**Stand 2**	**Stand 3**
	3.0	2.9	7.3	9.3	9.0	22.3
Male Coccyx	**Sit 1**	**Sit 2**	**Sit 3**	**Sit 1**	**Sit 2**	**Sit 3**
	0.8	3.1	3.3	1.9	7.3	7.9
	Stand 1	**Stand 2**	**Stand 3**	**Stand 1**	**Stand 2**	**Stand 3**
	0.7	4.0	0.4	2.4	15.4	1.5

Figure 4.8: Humidity measurement at 50 % to maximum and its peak.



Key: This graphs shows the female and male's thigh and coccygeal region as it progresses from cycles of sitting to standing. There are distinct peak in the male profile with the coccygeal region superseding the thighs. The female profile is more stable when compared, however the coccygeal region only slightly exceeds the thigh region.

4.4 Discussion

The studies presented so far, have showed that humidity sensors are able to measure changes in humidity over prolonged sitting and intermittent sitting durations. Sensors are able to reliably quantify the changes in water vapour that originate from an individual's skin (BMI and sweat response). The output of sensors appears sufficiently reliable, based on the sensor testing carried out in Chapter 3 (regular recalibration over time using systems traceable to National standards). The studies in Chapter 4 indicate that the humidity sensors can be used to measure the sitting interface humidity, which if applied to monitor dementia residents in care homes, could potentially quantify water vapour permeation through incontinence pads. As incontinence pads have a degree of breathability, humidity sensors would be able to detect the degree of wetness and be used to respond rapidly to potentially damaging saturation of the incontinence pads. Table 1.1 links the outcomes of the sensor tests in Chapter 3 to the studies in Chapter 4.

4.4.1 A kinematic study of prolonged sitting durations

Without the presence of any coverings, there was a significant difference ($p < 0.05$) between the sensors measuring the thighs and the coccyx for all participants (Thighs: (48.6 ± 1.0 %RH; range: 42.9 - 50.9 %RH]; Coccyx: 53.2 ± 1.5%RH; range: 43.8 - 56.4%RH). The male participants had lower thigh humidity (51.1 ±1.7 %RH; range: 40.9 - 55.2) than their coccyx (55.7 ± 1.7 %RH; range: 40.7 - 61.9). The female participants also had lower thigh humidity (46.1 ± 1.7 %RH; range: 36.4 - 47.3) than the coccyx area (50.8 ± 1.0 %RH; range: 38.6 - 51.9). Males generally had higher humidity's than the females. Differences were also found using descriptive statistics and interestingly the coccygeal areas still measured higher humidity when the sensors where covered and also when encapsulated in bags. Sensors when covered measured close to sensor in bags indicating that both conditions measured change. Males generally had higher humidity's than females when seated on three surfaces. For both sexes, the coccyx was still higher than the thighs. For temperatures, the males had slightly higher temperatures under the coccyx, however females had higher thigh temperatures (Coccyx: males (32.6 ± 1.8 ^{o}C; range: 30.4 - 35.6 ^{o}C) and females (32.1 ± 0.9 ^{o}C; range: 30.9 - 33.4 ^{o}C); Thighs: males (27.9 ± 1.2 ^{o}C; range: 31.9 - 35.0 ^{o}C) and females (32.4 ± 1.2 ^{o}C; (30.8- 33.8 ^{o}C). The lowest means were found at times 'start' and then at 50 minutes for all three sitting surface at both sitting locations however the coccygeal region remained higher in humidity. There may be more airflow surrounding the coccyx area due to its anatomical shape. The crotch area might be responsible for producing humidity during sitting, and so, the sensors are picking up higher humidity. The surface area of the thigh anatomy may seal the sensors and contain them in this atmosphere for the duration of the sitting. The thigh region is known for not producing as much humidity as the coccyx region which would explain the lower range in humidity detected. Sensor attachment and positioning for skin measurement in the sitting activity may be a challenging task and usually include skin attachment or seat attachment (Ferrarin and Ludwig, 2000; Liu et al., 2011). Skin sensors attached to the body to measure the seat-person interface would not accurately capture skin and seat material properties (Liu et al, 2011). For example, the attachment of sensor to skin yields the risk of creating a microenvironment in the skin region and possibly causing limited occlusion of arterial and venous flow, resulting in the alterations of blood flow to the area by vascular compression or altering heat loss mechanisms and thus affecting the temperature being measured. Problems of prolonged measurement with sensors attached to the person or skin which also interfaces with a sitting surface could increase local ischemia and thus increasing the occurrence of reactive hyperaemia (Liu et al, 2011). It has been reported that it can be challenging measuring interface pressures between the skin and supportive surfaces due to the perturbing effect of the sensors upon conditions at the interface (Ferguson-Pell et al 2009) and in addition small pressure-sensing devices may only detect the average pressure over a small surface area (Minns and Sutton, 1984). The sensors are limited to measuring the area equivalent to the size of the sensors and they are in contact with the skin surface which could promote a pressure reaction (Stewart et al, 1980; Finestone et al, 1991). Due to the cognitive challenges faced by dementia sufferers, the additional impingement of sensors attached to their skin or visible to them may cause them to be aware of the sensors which may lead to feelings of confusion or distress (unpublished observation). Conversely the sensors attached to seat needs to be carefully set-up because due to the sitting compressions, the polyurethane foam (or any foam) may partially push out the probes that were in the cushion (Vlaovic, Domljan and Grbac, 2012). In the author’s study it has been indicated that multi point measurements are better than single point measurements when studying the sitting (McCarthy et al., 2009; Ziu et al., 2011). Combinations and number of sensors have been used in previous studies however there is currently no consensus on the optimal location of sensors (Cengiz and Babalik, 2007; Ferrarin and Ludwig, 2000; Liu et al., 2011). The relative consistency of data from the same measurement position may be questionable when the seat materials change (Liu et al., 2011) as shown in authors study. However for the purpose of humidity detection of incontinence it may be that most suitable sensor locations would be one where variations in humidity levels could be easily detected quickly and continuously. This was found to be at the coccygeal region where it was consistently higher in humidity than the thigh regions. Attachment of sensors to the skin was avoided because it was believed that it could contribute to local pressure which may alter the local changes measured (Figliola, 2007). Additionally they may exert a similar phenomenon to the ‘white coat syndrome’ (where patients is affected by the clinical environment and are not able to relax which may affect the measurement) where the clinical environment may affect the person in such a way as to alter their sitting profile to a point where it does not relate to the normal position or interaction with the seat (Ferguson-Pell, et al., 2009). In the authors’ study the method of embedding sensors in the foam seat did not interfere with the participants seating profile (Liu et al., 2011) therefore this should be a key method used when considering seat measurements of an incontinence dementia sufferer. It has been suggested that there may be crucial biomechanical differences between males and females in sitting (Dunk and Callaghan, 2005; Mier and Shapiro, 2013). One study reported that there may be other factors unknown that relate to this difference and the interesting observation from the point of view of this study is the pelvic position (Mier and Shapiro, 2013). Women were found to be able to achieve greater hip flexibility however this may appear to be determined by the spinal curvature and pelvic position (not studied in this thesis) and not just hip joint flexibility. It was found also found that females could be encouraged to reduce muscle activity by using the back rest more consequently males are may need to increase their lordosis through greater lumbar support (Dunk and Callaghan, 2005). The difference between the humidity’s in subjects appeared to be also related to both the subject’s mass and movement habit for the one hour sitting period (27.7 ± 5.2 %RH; (21.1 - 37.4 %RH) (McCarthy et al., 2009). The difference of thermal comfort between males and females however are considered to be small (and dependant on clothing) in relation to skin temperature when in sedentary (Ellis, 1953; McIntyre, 1980; De dear and Fountain, 1994; Donnini et al., 1997; Lan et al., 2008). It has been reported however that in cool conditions females tended to be cooler than males (Parsons, 2002), however when a survey carried out in an office reported that females were 3.1 ^{o}C higher in temperature than males (Junta Nakano, 2002). Another study revealed that females preferred higher room temperatures than males, and were both uncomfortably cold and hot more often than males (Karjalainen, 2007). These studies were more subjective however in one laboratory study the gender difference in thermal comfort of Chinese people were investigated in a climate controlled environment (18 °C – 32 °C), by measuring their skin temperature at 17 different sites on the human body (Lan et al., 2008). These studies showed that woman feel comfortable at an operative temperature (26.3 °C) that is higher than the males 25.3 °C. In the authors study the fact that both the male and female participant has lower thigh humidity than their own coccygeal region strongly supports the use of more than one site of measurement when assessing the microclimate between the person and seat interface. In addition to this the fact that overall males had a higher humidity profiles for both coccygeal and thighs regions indicate that there are differences in both sexes.

4.4.1.1 Reactions to seat surface

When all participants sat on the three surface conditions, The interaction effect between the sensor location (thigh and coccyx) and the sitting surface groups was not statistically significant ($p > 0.05$). However through descriptive analysis the coccyx was slightly higher (maximum values) than the thighs in general on all three surfaces. The sensors in bags measured similarly to sensors under a cover for all surfaces (thighs: cover (39.4 ± 2.1 %RH) and bags (40.2 ± 0.9 %RH; coccyx: cover (46.5 ± 2.5 %RH) and bags (47.2 ± 1.8 %RH). Sensors with no cover measured the best. This indicates that sensors are able to detect changes from a human subject from under a cover and also when encapsulated in a bag of the same material. It has been reported that heat and moisture changes on and at the interface between the person and seat is strongly connected to the size of contact area and the pressure therefore it is important for the material covering the surface to transfer this heat and moisture away (Zacharkow, 1988). Below a certain degree of sitting compression, heat and moisture may mostly get transported to the surface layer of a seat however determination of the comfortable temperature may be determined by the individual’s variation in their body temperature (Hanel et al., 1997; Shitzer et al., 1978). It has been reported that thermal comfort is related to body temperature and that ‘the ideal” environmental temperature varies with every person over a time duration. Besides temperature, the human body constantly excretes moisture (liquid) either through the skin in the form of sweat or as urine through excretion (Vladovic, 2012). During sitting a person may perceive humidity on the skin surface as a discomfort as the moist skin could increase the friction coefficient causing the sensation of sticking to clothing or chair material, thus making shifting of body mass awkward (Reed et al., 1994; Stumpf et al., 2002). The increase in friction coefficient may cause, together with a pressure increase, skin blisters and, finally, surface erosion (Sulzberger et al., 1966; Dinsdale, 1974; Nicholson et al., 1999). Based on a 60 minute duration of continuous sitting, it had been reported that although recorded temperatures changed rapidly (on initial sitting) it was followed by a relative ‘plateau’ phase reached after 15 - 20minutes (McCarthy et al., 2009; Ziu et al., 2011). It was important to find out the actual humidity of the sitting environment of the healthy individual so that standard thresholds could be used to understand the measurement ability of the sensors. There has been varying suggestions on the most optimal sitting duration for reliable measurement although these are mostly for temperature measurements. Optimal time durations in sitting have not been widely investigated for humidity measurement (Table 4.1). Research into characteristics of slow regenerating foam with half-closed cells (mark CF-45) demonstrated that mechanical characteristics are very much dependant on temperature and humidity, but these effects were not researched in sitting experiments (Davies and Mills, 1999; Davies et al, 2000). The distribution of pressure while sitting on slow recovery PU foam was researched and it showed that when a 25 mm thick layer of such foam is exposed to the temperature of 35 °C and relative humidity of 80 %, it takes two hours for humidity contents to achieve equilibrium (Davies et al., 2000). Chair made from polyurethane foam such as office chairs are usually covered with materials with insulating abilities and preventing in this way the withdrawal of heat from the body and limiting evaporation (quoted in Stumpf et al. 2002; Bartels, 2003; Nicholson et al., 1999). It is probable that short sitting tests were mostly affected by air circulation, not so much by humidity input (Davies et al., 2000). It has been suggested that apart from the foam composition, the water vapour permeability of the seat may depends on the sitting pressure which varies for people, depending on location or magnitude of pressure exerted on the surface (Diebschlag et al., 1988). In a study observing different materials used for wheelchair seat cushions there was a significant rise in skin temperatures under the thighs and sitting bones of test subjects sitting on 10 cm thick foam rubber pads found (Fisher et al. 1978; Stumpf et al., 2002).

4.4.2 A kinematic comparison between sit and stand patterns

At the beginning of the sitting duration, the participants fidgeted to get comfortable. Towards the end of the sitting duration however a similar fidgeting behaviour occurs because the person may be aware that the experiment is ending and their sitting may not reflect a natural sit. In all the sitting cycles the coccygeal region for all subjects, were higher in humidity than the thighs. This indicates that the coccyx area has an area of higher humidity than the thigh area, even in short durations of sitting. In standing, sensors are able to recover however they may need more than 10 minutes to equilibrate back to the ambient room humidity. However, even with repeated sitting, the sensors manage to measure similar levels of sitting humidity each time indicating that the sensors may be reliable for multiple sitting and standing activities. The minimal difference between the male and females in the sit and stand study may be to do with the short time there is to capture any difference. Any physiological differences between the male and female in sitting may be studied for longer sitting periods (as demonstrated in the prolonged sitting study above). Duration sitting test of over 60 minutes was avoided because according to McCarthy et al., (2009) because a plateau phase was reached at the point of 15-20 minutes after sitting (Ziu et al., 2011). This study demonstrates that the 10 minute cycle is too short to determine the plateau phase.

Elderly people (mean age 75 and over) exhibit increased weight transfer time and decreased reaction time in general. It has been reported that the elderly takes an average or of 2.3 seconds to rise from sitting (n = 55) although it is common for them to take more time. Young people can perform the sit to stand task usually in less than 2 seconds (Papa and Cappozzo, 2000) which was appropriate for the authors study in determining the reactivity of the sensor detection capabilities. During a sit to stand phase the older people lack forward propelling power, and rely on lower limb power of which muscle strength had decreased with age (Arcelus et al., 2011). It has been suggested that more interruptions in the sedentary time was beneficial and associated to metabolic risks, triglycerides and 2-h plasma glucose (Healy et al., 2008). In terms of bed departure times there was a significant difference ($p < 0.001$) between young and older people (age: 18 - 80 years). It has been suggested that the outcome of the sit and stand patterns may reveal levels of impairment in postural control and muscle function. In particular osteoporotic women exhibited greater trunk movement compared to women with less bone loss (Trevisan et al., 2012). The principal resonance of both sitting and standing has been reported to be 5 Hz in sitting however slightly higher in standing (less than 1Hz higher). The standing body has more damping than the seated body. When standing the mass may be influenced by the tissue compliance of the lower limbs which work as a natural transmission path for vibration. However in sitting the head, torso and pelvis, move away from this damping transmission path thus redirection the damping properties to the seat surface. Although at the seat surface there may be new vibration factors (Matsumoto and Griffin, 2000). In the elderly, postural instability is more prominent. During sitting and standing however the perturbations of velocity profiles of trunk are noticeable upon getting off a seat to a standing position as well as sitting on the seat into a sitting position. The incapability of the elderly to mobilise their trunks during sitting and standing causes them to fall back when sitting down and lose balance upon standing up (Mourey et al., 1998). This was why it was important for the author to determine that the sensors are able to detect changes when with or without contact of the human participant. However it is not known whether incontinence affects this pattern yet. During the process of aging the body undergoes changes in the physiological and neurologic aspects (Healy et al, 2008;Hamilton, Hamilton and Zderic, 2007; Dunstan et al., 2004). These alterations include the decrease in bone mass, muscle strength, joint rigidity, ranges of movement, and the decrease of nerve conduction velocity in the central nervous system

(Deschenes, 2011; Trevisan et al., 2012) which in turn affects the motor strategies of the elderly (Demirbuken et al.,2011). One particular concern in the elderly population is the motor strategy of moving from the sitting to stand position which seems to increase the chances of falling especially in independent living people (Demirbuken et al., 2011). According to Demirbuken et al., (2011), there is lack of data on how motor strategies can achieve the sit to stand task in the elderly, by means of musculoskeletal functions (postural swaying, weight transfer times, and the exerted force during the rising phase. In addition to this no studies on sitting humidity's have been found by the author either. It was found that in balance tests, low scores were achieved when people took longer to stand up (Podsiadlo and Richard, 1991). This including many clinical studies has regarded the ability of standing up from a chair, as a predictor of functional independence and of falls (Gill, Williams and Tinetti, 1995; Campbell, Borrie and Spears, 1989). One reason that a person might choose to make a shift from sit to stand could be the desire for going to the loo (Getliffe and Dolman, 2007). Although the author's study focused on humidity's of the sit and stand patterns in healthy adults, it would be interesting to find out how moisture from incontinence could be detected from the elderly in sitting. Many elderly people especially dementia sufferers who reside in care homes, spend a lot of time sedentary whether during meal times, activities and relaxation or social times (Healy et al, 2008). The reason for them to be primarily sedentary is due to their lack of motor coordination. As a result of this any occurrence of incontinence could happen at any time during the sitting activity. Due to the slow movement of this group of people, sensors embedded in seats might be effective at detecting and alerting carers when incontinence occurs. As the sensors are able to detect changes quickly during sit and stand it could be used to determine moisture changes if at all present (such as leaks from pads). The affiliation of the sensors embedded into the seat takes away the idea of 'tagging' the individual and therefore may contribute to the protection of the individual's dignity; the primary focus for dementia people residing in care homes.

4.5 Conclusion

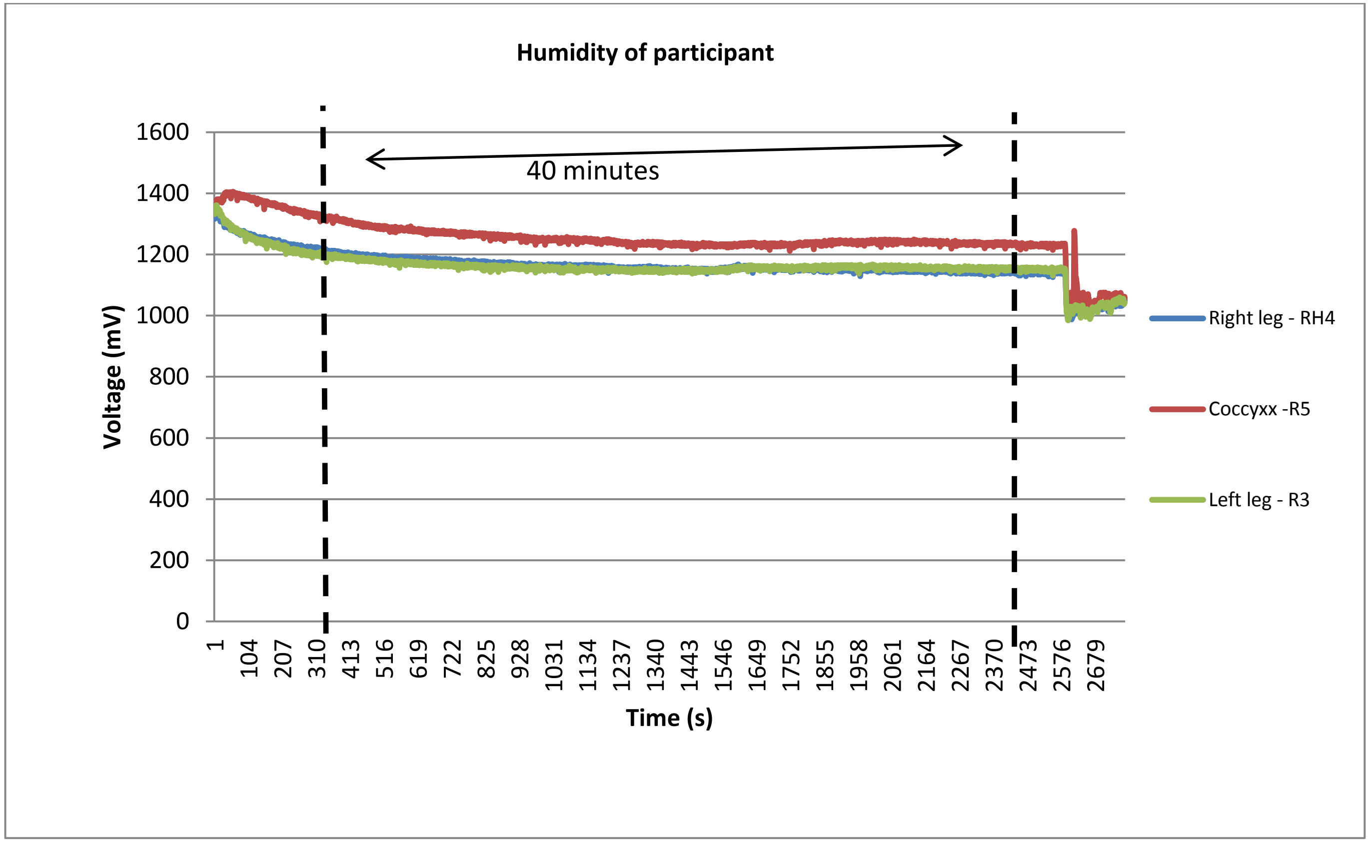
4.5.1 A kinematic study of prolonged sitting durations

There was a very small difference between the males and females in the n = 2 and n = 11 studies at both locations: the thigh and coccygeal regions. The male's appear to have higher humidity's for both the thigh and coccygeal regions. Although in general the coccygeal region has higher humidity than the thigh region. In addition the coccygeal region is still higher than the thighs when in contact with the varying seat conditions. Similarly the males still have slightly higher relative humidity than the females when in contact with varying seat conditions. It was observed that sensors encapsulate in bags appeared to measure a similar to being covered with a material. Encapsulating sensors in thinner materials may address the lagging factor experienced. Encapsulating sensors in water impermeable vapour permeable material (such as a commonly used wheelchair seat cover) and then embedding it within the seat may help to prolong the life of the sensors. Since this system is based on water vapour detection, it could be an effective method to determine the onset of incontinence through increasing water vapour present rather than having to detect the actual moisture itself. It appears that carers are not interested in sensors that they have to physically clean due to urine contact as it adds extra work. Water vapour detection could evade this problem of cleaning and embedding it within a seat with a protective material encapsulation could encourage infection control. The differences in magnitude between the thighs and coccygeal region suggest that multipoint measurement would yield a difference in results. Single point measurement could be considered provided the best placement is determined. These studies have shown that the coccygeal region anatomically produced more humidity when in seated than the thighs (which are assumed to create a seal with the surface). It could be argued that as long as the sensor is able to detect humidity over the thighs region, it could be a good location for sensor placement. Due to the anatomical structure of the coccygeal region in sitting it is normally prone to sweat and also the first contact during urine expulsion. In an incontinence sufferer, an incontinence pad may inhibit the humidity's that were picked up by this experiment. If leaks in the pad were to occur, or high humidity was exuded from the pad itself the humidity sensors may be able to detect the saturation levels of the vapour and determine assistance if needed. The coccygeal region consistently measure higher humidity's even when the varying masses of individuals in the study sat on the same cushion dimensions and identical sensor location with the addition of wearing jeans. This could suggest that the area measured under the coccygeal region was reliable for the purpose detecting this region and also repeatable.

4.5.1.1 Limitations and future considerations

Undertaking the study was time intensive and there was lengthy interaction for the participant in sitting. All participants (n = 11) sat on each surface once due to time limitations. Additionally the sensors in bags with an additional cover were not analysed for these multiple participants because of time constraints. The two participants were able to sit on each surface six times because they were less in numbers compared to the larger group thus being able to commit to this study. All participants were requested to sit on each surface for a period of 50 minutes, although only forty minutes of the data were analysed (figure 4.9). At five minutes in and one minute before the end of the fifty minute sitting duration the author would alert the participant and this is may have caused the participant to anticipate coming off the seat may have contributed to the observed variation of the data. Although this was not recorded directly figure 4.9 shows raw data for a single participant observed for the first five minutes (300 seconds) and last five minutes (2400 seconds onwards) illustrating the equilibration variability which differed between subjects. Based on the group variability, the limits were decided by the author. The data chosen for analysis can be seen in figure 4.9, between these times as marked by the black dotted lines. The experiments carried out by the author were done during the spring time for which the indoor environment would be that of a care home environment (20 °C temperature and 40 %RH humidity). Each person from the multiple group of participants (n=11) sat on the three surface conditions for a total of 2 hours and 30 minutes. The single male and female participant each sat on four surfaces (each surfaces was sat on six times) and in total each participant sat for 20 hours. As these participants were healthy, careful consideration should be taken if the study should be emulated for investigating the sitting effects of dementia sufferers residing in care homes. The setup of the sensors being encapsulated and embedded on a contoured foam cushion meant that the participant are allowed to maintain the exact sitting position for periods of time without feeling the interference of sensors. This might be a useful technique in order to study the microclimate of dementia sufferers in sitting. Long term study in this could identify threshold patterns of humidity in this group of vulnerable people and threshold of humidity’s could be used for incontinence detection. Since this group of vulnerable adults also spend a lot of time in sitting and who already may have weak postures, they could benefit from the added value of having a posture assisted seat (contoured) attached to a standard sofa or dining chair.

Figure 4.9: Description of the time analysed



4.5.2. A kinematic comparison between sit and stand patterns.

The humidity sensors were found to react instantaneously upon a subject sitting as well as standing and this was consistent between the three cycles of sit and stand. This may suggest that the humidity sensor measurement of the surface at the person- seat interface reacts quickly to the cycle between sit and stand. The little difference between the male and females in the sit and stand study may be to do with the short time there is to capture any difference. It could be possible that this study has shown that any physiological differences between the male and female in sitting could only be studied for longer sitting periods as shown in the longer duration tests. Techniques of measuring the behaviour in sitting and standing appear to be carried out through the use of vibration sensors, pressure sensors, accelerometers, magnetic fields, video recordings or motions analysis using optical sensors (Demirbüken et al., 2011; Arcelus et al., 2011; Healy et al., 2008; Matsumoto and Griffin, 2000; Mourey et al., 1998). All the studies above also show an examination technique based on a kinematic approach and the body orientation to the sitting surface or the relationship between the sitting and standing postures (Arcelus et al., 2011; Nuzik et al., 1986). None of the studies above attempt to monitor the physiological factors involved in the sitting surface and how it recovers when the surface is relieved of the pressure. The authors study utilizes humidity sensors which will display the microclimatic behaviour at the seat and person interface. Thie met the aim of this study which was to use humidity detection to contribute the findings which could develop the understanding of the sit to stand behaviour from a physiological perspective that is nonintrusive to the person. To the author’s knowledge this was successfully done although no other studies were found in the literature which observes humidity during the activity of sitting and standing.

4.5.2.1 Limitations

The timing for sits and stands were determined by the author using a stop watch timer separate to the times determined by MS Excel as the data got collected. Although the author took great care in starting the stop watch to carefully coincide with the timing of collection of data, human error in prompting the timing device may have appeared. Delays were also contributed by the subjects who did not respond immediately to the authors prompt of the sit and stand. To improve this audible alarms connected to a timer which is synchronised to the data collection software could increase the accuracy of exact measurement.

Chapter 5

Synopsis of results, general thesis discussion and conclusions

"The number one benefit of technology is that it empowers people to do what they want to do. It lets people be creative and productive. It lets people learn things they did not think they could learn before and so in a sense it is all about potential." – Steve Ballmer.

This chapter presents the synopsis of results carried out in this study, taken forward by a discussion of the relevance of the studies to the overall aims and objectives of the research. It should be noted that there were three separate studies which are presented earlier in chapters 2, 3 and 4. In order to present the discussion in a coherent way, this chapter will basically present: the care home study, the sensor technology study and the sitting study. The linkages that bring together these three separate studies are then presented in a combined way before the conclusion is presented.

5.1 Synopsis of results

Prior to the presentation of the general discussion of the thesis, it would be useful to present in a figure, the results of analysis presented separately in chapters 2, 3 and 4. This is shown on Figure 5.1 below. The table following that (Table 5.1) shows the linkage between the chapters two, three and four and how they combined to develop an idea for a prototype.

5.2 General discussion to the thesis

It is evident from the analysis earlier in Chapters 2, 3 and 4, that this study was able to demonstrate carer perceptions on using sensor technology to manage incontinent dementia residents in care homes. The carers interviewed were asked if such a system could help in the current management protocol of caring of incontinent dementia residents living in care homes. This study also objectively assessed the biological measures of humidity in sitting (healthy subjects) without invasive human contact (embedded within a seat).

Figure 5.1 : Collated conception arising from thesis

Person

For prolonged sitting: humidity at the coccygeal region is always higher than the thighs (irrespective of gender).

C = 53.2 ± 1.5 %RH
T = 48.6 ± 1.0 %RH

Males have higher humidity at the coccygeal region compared to females.

Male (C = 55.7 ± 25 %RH; T = 51.1 ± 1.7 %RH)
Female (C = 50.8 ± 1.0 %RH; T = 46.1 ± 1.7 %RH)

Sit and stand cycles: Sensors are able to change between sit and stand patterns. Sensors can recover (during the stand phase) as fast as it can detect sitting.

Sit : T = 3.5 %RH (A); 10.2 % (P)
C = 2.9 % RH (A); 9.45 % (P)
Stand: T = 3.4 %RH (A); 10.7 % (P)
C = 2.9 % RH (A); 10.0 % (P)

Humidity sensor detection

- **No human contact.**
- **Sensors measuring from within bags and embedded in seat or bed.**
- **Indicates humidity levels.**
- **Reliable and accurate**
- **Educating and supporting carers.**

Care management

Sensor technology may assist in management (71 % or 15 out of 21 homes).

- Carers need training and support

Sensor technology may not be embraced (24 % or 5 homes).

- Slows down management
- Fear of technology dependency
- Breach of patient confidentiality
- Prefer traditional caring approach

Behaviour is the key factor associated with the challenges of incontinence management.

Testing Humidity sensors

1. Existing sensors previously used for testing (McCarthy et al., 2009) aged within 2 years and lost accuracy (E = 9.45 ± 5.2 %RH; N = 2.16 ± 1.3 %RH).
2. Sensors may be dried using a desiccant. Drying increased accuracy (Before drying = 1.68 ± 2 %RH; After drying = 0.61 ± 3.71 %RH).
3. Sitting on a humidity sensor for 7 months may age the sensor but the errors are minimal and may be dependent on circuitry (5.48 ± 2.22 %RH).
   Sensors placed in the kitchen and exposed to heavy amounts of surrounding moisture (from kettle and food preparation) still performed acceptable with less errors (3.22 ± 1.69 %RH) than the seat sensor (5.46 ± 2.22 %RH). Powered sensors stored in darkness or light was not affected (D = 4.10 ± 1.15 ; L = 4.79 ± 1.98)
4. Sensors can detect humidity from under cover or when encapsulated in a bag. Both made from the same material (Invacare) (e: 1.3 – 2.5 %RH).
5. Sensors are sensitive to detecting the presence of moisture and when introduced at different distances (e = 0.3 – 0.6 %RH).

Key: C = coccygeal region; T = thigh region; A = Absolute change; P = Percentage change; E = existing sensors; N= new sensors; D = dark (drawer); L = light (wall); e = error.

Table 5.1: The linkages that bring together these three separate studies

Title	Reason for study	Outcome of study	Global Topics
Chapter 2 ***Perceptions on using sensor technology to manage incontinence in dementia***	To investigate the perception of carers in using sensor technology by determining the desired design of an ideal system that could work to detect incontinence in dementia residents.	Carers would like to use sensor detection technology in line with managing incontinence in dementia residents as long as training and support are provided.	Public engagement
Chapter 3 ***Performance verification of humidity sensors traceable to national standards.***	To verify the behaviour and address correct maintenance of sensors when exposed to controlled moisture conditions. This was done to determine if the desired design ideas (non-invasive, discrete and measuring from within a material for prolonged periods) could be understood in stringent laboratory conditions for reliable application for human subject measurement.	The humidity sensors can accurately measure a controlled environments (traceable to national standards) and ambient conditions for prolonged period of up to seven months. Sensors are able to detect changes in humidity reliably when inside a material.	Sensor verification
Chapter 4 ***Application of the sensors in a simulation of care home sitting activity.***	The sensors were found to be reliable and accurate in a controlled environment therefore it was dependable at measuring the humidity between the person and seat interface. The sensors were non-invasive and discrete because they measured from within a material and were embedded within a foam seat. The sensors were able to quantify humidity changes between different people.	Humidity sensors are able to detect different placement of sensors in a seat. It is able to reliably detect changes over prolonged (50 minutes) and intermittent (10 minutes) sitting durations.	Human application
Chapter 5 ***Synopsis of results, general thesis discussion, and conclusions***	Amalgamation of the Chapters two, three and four in order to conceive an idea for a potential prototype which could successfully detect incontinence in dementia residents in care homes.	By determining the needs of the carer, the reliability of the sensors and the accuracy of them when applied in sitting, it was possible to understand the feasibility of a prototype that would be suitable.	Product development based on consumer needs.

The sensors when combined with a micro weave seat cover (and encapsulated in bags of the same material: in a water impermeable, vapour permeable material embedded in a contoured foam seat) demonstrated good reliability and accuracy through laboratory testing and calibration (traceable to national standards). The relationship of the functionality of the sensors in these tested conditions were compared to the semi-quantitative questionnaire study which aimed to determine the perceived usefulness of a sensor detection based solution within the care home setting specifically to manage incontinence in dementia residents. In the older and infirmed it is particular complications of skin integrity which could shorten life expectancy (Matthew et al., 2008). The proportion of sedentary time was also found to increase with age for example older adults may be at the highest risk of developing metabolic related diseases (McNeill et al., 2006; Denys et al., 2009) based on the amount of time spent in sitting positions (Knuiman and Kramer, 2012). This may be because they are more likely to be occupationally sitting as well as increased health problems associated to older age (Bankoski et al., 2011; Matthews et al., 2008). This scenario is seen to an extreme in care homes where most ageing residents spend a large amount of time sitting (Care Quality Commission 2012). It is important to note at this point that the risks of sitting could be exacerbated if existing metabolic related diseases were already present, which is usually the case in the elderly (Healy et al 2008). It was estimated that physical inactivity causes 6-10% of the major diseases such as heart disease, diabetes mellitus and cancer, worldwide (WHO, 2008). Too much time spent in sitting and very little exercise could result in deleterious cardiovascular effects (increase of fat around the heart), metabolic syndrome (higher cholesterol, or triglycerides, high blood pressure, insulin resistance and waist line circumference or abdominal obesity) and cancerous effects (Hamilton et al., 2008; Ploeg 2012; Dunstan, Thorp, and Healy 2011; Dunstan et al., 2012; Healy et al., 2007). It has been suggested that sitting is related to shortened life expectancy (Daley, 2013).The physiological health consequences of sitting (Ploeg 2012; Vlaovic, Domljan and Grbac 2012; Craft et al., 2012) have been studied with particular emphasis on the area of pressure sores. Pressure sores may form when there is skin maceration due to sitting which appears to be the result of long term hyperhydration. Contact of the skin surface with a seat material is thought to create a microenvironment in which the humidity rapidly increases (Ploeg et al., 2012, Corlet, 2008). The increase in surrounding humidity, in parallel with a rise in skin temperature induces a further increase in sweating, which could effectively further increase skin hydration resulting in the weakening and damage to skin if unchecked (Getliffe and Dolman, 2007). As perspiration increases, there is a reduction in the capacity of evaporation to remove heat energy and this means that most of the sweat drips from the body and gets trapped within the fabric fibres of the clothing and seat (Das et al., 2007; Ferguson-Pell et al., 2009). The water vapour permeability of the interfacing surfaces such as seats covers or clothing due to a person sitting may be significantly quantified by the dynamic nature of heat transfer rates (Goldman and Kampmann, 2007; Das et al., 2007). The author demonstrated that the existence of humidity at the seat-person interface is measurable by monitoring the surface temperature and humidity (Stockton and Rithalia, 2007; McCarthy et al., 2009; Cengiz and Babalik, 2007).

Comparing brand new sensors (HIH4000-004) with used sensors (HIH4000-001; McCarthy et al., 2009) against a humidity profile yielded a difference. Used sensors performance may have been affected by their having been used(McCarthy et al., 2009; Cascioli et al., 2010). The published data in the McCarthy et al., (2009) study constituted of about 70 hours of testing (consisting of calibration experiments, laboratory testing and 1 hours sitting measurements from 10 subjects). Upon discussion with the authors of this study, pilot testing, preparations for experiments and re-testing of the published data were not recorded however are likely to have caused up to a year of frequent usage (HIH4000-001 Honeywell). Throughout this year, dust and water vapour can accumulate on the sensors increasing the risk of an electrical break down and cause a shift both offset and sensitivity (Lohbeck, 2008; Cavlier, 2012). Dust particles can coat sensor elements within a few months and cause a variety of problems which include electrical shorts. Ideally sensors should be cleaned and designed in a way to correctly insulate sensitive elements to prevent dust build up. Water vapour may also cause a safety risk and can come from many sources such as cleaning products, air coolers, food beverages, and from close proximity to the human body. A single person's breathing may produce up to a quarter cup of water per hour (Lohbeck, 2008). In addition to this the subjects who sat on the sensors in the McCarthy et al., study would have had transepidermal water loss through their skin (39.8 to 42.8 gm^2/hour) (Gray, 2014). Condensation may saturate dust coating on the sensing element and increase the conductivity between electrical circuits which could cause short circuits resulting in sensor damage, fire or electric shock (Lohbeck, 2008). In relation to the existing sensors over time, exposure to moist air and contamination of dust particles that deposit on the sensors materials may have caused the larger errors when compared to the brand new sensors. To continue using the existing sensors it would require periodic calibration (Cavlier, 2012). The frequency of usage was not entirely comparable with the existing sensors which is the reason why the endurance experiment was carried out. This was done by placing brand new powered humidity sensors in five locations (located in a student room and kitchen) over a span of seven month, whilst calibrating once a month to investigate ageing and hysteresis (Bull, 2009). In the prolonged measurement tests, the powered humidity sensor on the wall (exposed to light and ambient air), showed no difference in performance when compared to powered humidity sensor located in the drawer (darkness, lower changes in air movement) (Matsuguchi et al., 2000; Vaisala, 2010). This means that the sensors are not affected by dark or light environment. In a study investigating the characteristics of polymer materials, two specific types of polymeric sensors (polymethyl mthacrylate: PMMA and cross-linked polyimide:PI) showed little drift after 250 days of exposure to varying humidity's (40°C between 10 %RH and 90 %RH) however all four sensors (the other two were: cellulose acetate, CA and cellulose acetate butyrate, CAB) tested showed an increase in sensitivity after this same period (Matsuguchi et al., 2000). The HIH4000-004 Honeywell sensors exhibit the same changes in sensitivity and experiences drift because they are made from thermoset polymers which are primarily cross-linked polyimides (Honeywell, 2010; Dante, Santamaría and Martín, 2009). The sensor embedded in the seat was subjected to high frequency of sitting (Monday to Friday, between 9 am and 6 pm) which would cause high humidity exposure to the sensor. Prolonged sitting measurements on humidity sensors have been performed however none had been carried out for prolonged periods such as seven months (McCarthy et al., 2009; Cengiz and Babalik, 2007; Stockton and Rithalia, 2007). The time line of this test was important because if sensors were to be deployed in care homes to monitor sitting, they would need to measure all the time due to the high levels of sitting carried out by dementia sufferers (Care quality commission, 2012). It is important to point out that humans maintain constant body temperature between 36 ˚C and 37.5 ˚C however in still, ambient temperatures at 20˚, the skin surface temperature when clothed is between 31 ˚C and 36 ˚C (Ferguson-Pell,*et al.,*2009; Cheung, 2010). In a clinical study on humans on support surfaces the relative humiditys under seat buttock vary between 40 and 100% and temperature on the ischials vary between 30 and 37˚C (Nicholson et al., 1999; Cochran, 1980). The humidity at the skin support interface should ideally be between 40 and 65% and the interface temperature should not change by more than a few degrees (Nicholson et al., 1999; Cochran, 1980). Taking this into consideration and coupled with the transepidermal water loss of the subject (39.8 to 42.8 gm^2/hour), the embedded sensors did not seem to deteriorate over the 7 months (Gray, 2014). However it is not known what the effects of incontinence could have on this. Incontinence sensors are usually in contact with skin or embedded within a pad (Getliffe and Dolman, 2007) and have an array of reported problems which include unable to discriminate between levels of moisture, costly manufacturing, and additional cleaning (Lewis et al., 2012). The humidity sensors in this study was able perform well during monthly calibration by showing little sign of drift and although it may lose sensitivity over time (up to a year of consistent usage). It has been reported that calibration of a relative humidity sensors may be carried out 6 months to one year after deployment (Bull, 2009). Of all the powered sensors, the kitchen sensor performed the worst (ten differences found across the seven months). This could be due to the sensors exposed to maximum air movement from people, steam from the communal kettle, additional moisture from the sink and food preparations. Interestingly the unpowered sensor indicated a lot of difference (six times over the seven month period). It may be concluded that sensors are perhaps more reliable when continuously powered for monitoring sitting. The storage of unpowered sensors should be avoided as it indicated some deterioration. Over the duration of seven months the average humidity and temperature of the kitchen was higher than the room where all the other sensors were located (Kitchen: humidity: 49.2 ± 8.1 %RH, range 34.0 to 66.4 %RH; temperature: 22.6 ± 1.2 °C, range 20.0°C to 25.1 °C) (Room: humidity: 46.6 ± 6.7 %RH, range 34.8 to 61.1 %RH; temperature: 22.7 ± 1.1 °C, range 20.3 °C to 24.6 °C). Even though there was minimal ambient difference in the two rooms, the kitchen sensor exposed to higher moisture (located 600 mm above the steam outlet of the kettle) may have caused it to perform the worst. At normal atmospheric pressure, the maximum relative humidity above the boiling point of water is always lower than 100 %RH (Vaisala, 2010). This is because water vapour pressure cannot be higher than the total pressure therefore there will always be a limit on the relative humidity (at temperatures above boiling point). For example at a temperature of 120 °C, using the water vapour saturation pressure (1490 mmHg), the maximum relative humidity be calculated to be 51 %RH. In normal atmospheric pressure (760 mmHg), using the highest possible water vapour saturation pressure (also 760 mmHg) translates to 51 %RH (Vaisala, 2010). Since higher exposure of water to the HIH4000-001 sensors cause changes in its output it was necessary to investigate moisture sensitivity from varying proximities. In this study water drops were introduced when sensors measured from under a cover (polyethylene cover; used in wheelchair seat cushions).

When testing the sensor sensitivity to different moisture conditions, the sensors with no cover yielded no difference to sensors under a cover (without the introduction to water). When water was introduced the sensors measured changes in relation to water dropped on the following locations. A distinct difference was found between sensors measured the from under a cover (no water), water dropped on top of cover and at 1 cm away. This could suggest that sensors are able to detect humidity based on presence and location. Sensors detected particularly high levels of humidity when water was splashed all over the cover at a temperature of 37 °C. It is not known why the water dropped at 2cm away measured similar to the splash test. The splash test used 20 ml of heated water to represent the spread of urine over the cover to simulate incontinence (Getliffe and Dolman, 2007). The normal healthy bladder capacity is 500 ml with a flow rate of between 30 ml/s and 50ml/s (Getliffe and Dolman, 2007). Incontinence pads vary in absorbency to accommodate urine expulsion in diverse volumes ranging from a few drops up to more than 250 ml at a time. A pad may also be prone to multiple insults of urine prior to changing (Cusick et al., 2003). Urine that is immediately expelled from the human body will be 37 °C and has been successfully detected in a previous study using temperature detection (Cusick et al., 2003). The sensors are able to discriminate between the different situations especially with the introduction of water. There is a 8.5 %RH difference in the range of the water splash test, because of cooling. A change was picked up by the sensors 15-30 seconds after water was dropped. Regular recalibration and careful choice of microweave cover and sensors could increase and encourage a more consistent detection time. Even though the HIH4000-004 Honeywell humidity sensors are designed for moisture detection, it was important to investigate whether frequent exposure could affect their detection ability. The desiccant experiment tested the same set of sensors in two conditions before drying and after drying.

In this case there was a difference before and after the sensors were dried. The average error between the sensors before and after drying was: 2.79 ± 1.73 %RH; range: 0.95 to 8 %RH. The lowest errors for both conditions were found between 40 %RH (ascending) and 40 %RH (descending) (2.09 ± 0.75 %RH; range 0.95 to 3.99 %RH). This range fits in better with the manufacturer's accuracy (± 3.5 %RH) which is a positive result considering the sensors should ideally measure between 40 %RH and 65 %RH for sitting conditions (Cochran, 1980; Nicholson et al., 1999). It should be noted that due to variations in people it may difficult to use clinical measurements to compare support surface humidity for example in a clinical study on humans sitting on support surfaces the relative humidity under seat buttock reportedly varied between 40 and 100% and the temperature on the Ischial varied between 30 and 37˚C (Nicholson et al., 1999). Near the point of condensation (100 %RH) some capacitive sensors become inaccurate causing increased errors and calibration drift. Although the sensor may output the maximum 100 %RH limit, it could be that humidity's are the beyond tolerance which could cause internal damage to the sensors (Griesel, Niemand and Lanzinger, 2012). In addition to the sensors compared to one another, they were in turn compared to the climatic chamber. The sensors (before dried) measured lower than the climatic chamber (indicated by the negative sign as lower than the humidity profile) (-1.68 ± 2 %RH; range: -4.17 to 3.14 %RH). After drying, the sensors measured with less errors (0.61 ± 3.71 %RH; range: -5.61 to 7.56 %RH) and slightly above the chamber setting. This means that exposing sensors to a desiccant appeared to dry the sensors and making it more sensitive to detection. The same desiccant product used in the authors study was also used in the McCarthy et al., (2009) study. Although the author re-set the desiccant by drying it in a vacuum, it would have been interesting to use a new batch of desiccant with a known specified humidity. In the McCarthy et al., (2009), the desiccant brought the same sealed environment down to 3.1 ± 0.2 %RH where as this study it was brought down to 22.9 ± 0.3 %RH for the same duration of 48 hours. This indicates that the desiccant has changed in its known humidity through time and previous usage. Recalibration of the desiccant may not have re-set its drying properties. Both experiments however showed that the sensors measured very low errors (± 0.2 %RH and ± 0.3 %RH) that were within the manufacturer's accuracy limits (± 3.5 %RH). Honeywell sensors are capacitive sensors and they have the ability to fully recover from condensation with reasonable resistance to chemical vapours. The typical uncertainty is usually ± 2%RH although the errors found in this study were far lower (± 0.3 %RH). The capacitive sensor consists of a thin film polymer deposited between two conductive electrodes (Roveti, 2001). When this polymer absorbs water it occupies the free space between the polymeric molecules and the weight of this is proportional to the relative humidity. In other words, the change in dielectric constant of the polymer is linearly proportional to the amount of water absorbed (Chen and Lu, 2005). Even though the sensing surface is coated with a porous metal electrode to protect it from exposure to contamination, hysteresis is usually a serious problem in capacitive sensors (Roveti, 2001; Chen and Lu, 2005). Hysteresis may occur when water is absorbed in the polymer as clusters. The formation of these clusters indicates that the hygroscopicity of polymers may be high which could lead to large voids in the polymeric structures. In the manufacturing process of capacitive sensors a method called cross linking which uses polyimide insulators may be used to insulate the polymers in order to enhance sensitivity and resolve the deformation and aging caused by the polymeric voiding of water clusters (Chen and Lu, 2005; Matsuguchi et al., 2005). Exposing the sensors to a dry environment (22.9 ± 0.3 %RH) has removed moisture from the sensing surface and element. In a similar study heated sensors showed better performance than unheated sensors (unheated: mounted in a saturation chamber at 20 °C at different humidity's; heated: exposed to heated saturated air to force condensation, 40 °C at humidity's over 100 %RH) over 3 hours. The continuous high humidity could cause condensation at the sensor surface and within the element. Water condensation on humidity sensors may make it read at a maximum 100 %RH and if it is higher it will not be known. It will remain at this level until all liquid water evaporates from the sensor. The long term drift of repeated condensation is negligible in capacitive sensors although drift may increase when exposed to high amount of dampness for a prolonged period (Vaisala, 2010). If sensors are unable to withstand the high humidity data acquisition may be cut off (Griesel, Niemand and Lanzinger, 2012). Drying out the sensors using a desiccant could be a method used in addition to calibration so that sensors may be maintained to output reliable accuracies. Careful design and installation and possibly protecting the sensor with a material can avoid condensation and further damage (Vaisala, 2010). Investigating HIH4000 Honeywell sensors over time has shown that even with increased exposure to moisture performance could get affected. The addition of a protective insulation cover could protect this even further (Lohbeck, 2008). There have been a few sitting related studies that have measured temperature and humidity though a materials however none were encapsulated in a bag (Ferguson-Pell et al., 2009; Brattgard et al., 1975; Cengiz and Babalik, 2007; Nicholson et al., 1999; Cochran, 1980). In one study subjects sat on an experimental seat in a climate controlled room for 90minutes and the temperature and humidity in the sitting area were continuously monitored on an experimental seat (Brattgard et al., 1975). Fourty different seat materials were used and with respect to the temperature and humidity and seat materials they were broadly divided into three groups; hot (plastic coated cloth) , warm (sheepskin, towelling) and cold (Non-woven plastic or raffia). The groups names relate to the average skin temperature when exposed to that either hot (37 °C), warm (33 °C to 35 ° C) and cold (31 °C to 33 °C). Sensors were able to measure changes in humidity and temperature from under all three categories of material (tested at 20 °C and changes in humidity from 40 %RH to 65 %RH and the differences were: hot (2 %RH increase); warm (4 %RH increase); cold (4 %RH) (Brattgard et al., 1975). The hot surface might cause the microclimate of the sitting area to dry thus decreasing the sitting humidity. The warm and cooler materials performed better by retained higher humidity's. These differences prove that sensors are able to detect variations in humidity through different materials which inspired that author to test it from an encapsulated set-up. In the authors study, sensors are able to measure from beneath a polyethylene (wheelchair cushion cover) however other materials (sewn into a bag for sensors to be encapsulated in) were also investigated. These materials are listed on table 5.2; it is believed that the thickness and moisture vapour transfer rate may have influenced the measurement. When individual sensors, encapsulated in a sewn bag made from different materials were compared to a sensor with no cover, a significant difference was found ($p < 0.05$; two-tailed).

The sensor which was encapsulated in a bag with an additional cover over it (both made from polyethylene wheelchair cushion cover; Invacare deep plus cover Invacare Ltd.) performed the worst (16.2 %RH error). This was followed by the surgical glove material (13.8 %RH), thick plastic (11.4 %RH), thin plastic (12.8 %RH) and pore tape (12.2 %RH). A reduction in errors were found when sensors were encapsulated in the Invacare deep plus bag (6.3 %RH) and woolly glove (5.7 %RH). Exposed sensors (no bag or covering) performed with very low errors (2.5 %RH) which is expected. However when the sensor was covered with an Invacare deep plus cover the errors were the lowest (1.6 %RH). Both of these two conditions gave errors within the accuracy of the manufacturer's data for Honeywell sensors (HIH4000-004: ±3.5 %RH). These sensors are able to measure through loose material placed on top without the restrictions of the dimensions of a bag. On table 5.2, the Invacare deep solution cover had the best moisture transfer rate which relates to the error. The slightly higher errors found when the same material was sewn into a bag, may mean that the design of it could be changed. In this case the method of encapsulation might need changing to a larger dimension for more space and breathability and also different thickness of material. It has been reported humidity sensors would need additional insulation in addition to the basic insulation provided on the element itself. High amounts of surface contact with dust and relative humidity will reduce the life expectancy of the product and reduce its sensitivity (Lohbeck, 2008). This led the author to advocate that the sensors should be recalibrated between 6 months to 1 year to maintain accuracy.

Table 5.2: Materials used in the experiment and the properties found in literature.

Material	**Material description**	**Thickness (mm)**	**moisture vapor transfer rate (mvtr) (g/m^2/24 hours (from literature)**	**MVTR measured at**	**References**
HDPE thick plastic	High density polyethylene	0.08	4.7-7.8	38°C and 90 %RH	Polyprint 2008
LDPE thin plastic	Low density polyethylene	0.02	16-23	38°C and 90 %RH	Polyprint, 2008
Woolen gloves	100 % wool	1.14	230	-	Ireview gear.com, 2010
Clinical gloves	Polyvinyl chloride	0.1	2.4-4	38°C and 90 %RH	WHO, 2007
Pore tape	polyethylene film	0.25	400	40°C and 80% RH	EP0262786 A2 (1988)
Invacare Deep solution	Low density polyethylene	1	2170	***100 °C and 90 %RH***	Invacare, 2010; Ralston, 2010

The requirement of periodic recalibration is important in addressing deviations in the sensors detection system specifically if the sensors are used for high demand applications (Cavlier, 2012) such as monitoring incontinence on a daily basis. There is no specific indication on how long a calibration may last for. The length of time could range from a few months to a year or even more depending on the usage and the environment it is in (Cavlier, 2012). The sensors in the authors study demonstrated loss of accuracy after heavy usage (2 years as well as continuous usage (7 months). It is inevitable sensors lose accuracy and require their calibration at some point. Based on the testing carried out this in study it may be necessary that incontinence sensors used to detect continuous levels of humidity (between 40 %RH and 60 %H and some times higher) may be required to undergo calibration between 6 months and 1 year (Cavlier, 2012**;** ISO/TS 16949:2002). This will ensure that the reliability and accuracy of the system will be accurate and reliable. It has been reported in many studies that carers who look after dementia sufferers have higher levels of burden than carers caring for people with physical disabilities (Gonzalez-Salvador et. al., 1999; Ory et al., 1999). Incontinence is distressing to the caregivers and may cause the loss of dignity to the sufferer (due to limited awareness), ultimately leading to care home admissions (Biswas et al., 2008). Carers find coping with incontinence physically demanding and exhausting when associated with the behavioural challenges that come with dementia sufferers (Upton and reed, 2005). Dementia sufferers who are unable to comprehend and communicate effectively, may get agitated or emotional during routine checks, which can be invasive (Getliffe and Dolman, 2007; Leung et al., 2008) or as the result of simply being wet from UI. It is also noted that tasks such as checking, changing and toileting dementia residents take up the majority of the job role. Managing incontinence in patients with dementia would be easier if communication is improved (Price, 2011). Research has shown that using technology to monitor the health of dementia residents in care homes have been reported to help by allowing a better night's sleep, less anxiety, improved relationship and positive outcomes or autonomy for person cared for (Jarrold and Yeandle, 2009). The resident may be unaware that they need to be checked, changed or need the toilet and it is due to this sensor detection technology may be of benefit to inform carers on the incontinence status of the resident. Especially if sensors are wireless and embedded within a bed or seat. Sensor detection technology that notifies when UI has occurred may reduce unnecessary visits and pads checks and allow immediate action (Palmer, 2008). It has been estimated that the time for carer checking on soiled pads can be reduced by 50% through the use of an automated detection system (Biswas et al., 2008). A trigger or alarm system used to raise an alert has allowed carers to reduce unnecessary checking respecting dignity and to ensure potential problems are addressed quickly (Buckley, 2006). Carers that have experienced the use of incontinence detection technology have reported feeling positive about technology and the relief it gave them (Dunk and Doughty, 2008). In terms of the dementia sufferers, the carers reported that technology allowed for a better night's rest, reduced fears from intrusion of checking, and reduced worry (Wai et al., 2008; Dunk and Doughty, 2008; Getliffe and Dolman, 2007).Most incontinence sensors designed for hospital or care home application, consist of sensor that are placed inside incontinence pads with wireless transmission technology that can alert carers of a voiding event (Wai et al., 2008; Nilson and Gullikson, 2011; Simvita, 2012), however they were not utilised in the homes that were interviewed in the authors study. The carers from the questionnaire study who supported the idea for technology, has expressed that a sensor based solution should not be used alone but rather in line with their current management protocol. A sensor based solution may help to alleviate the burden of care in relation to the incontinence sufferer's behaviour after an incontinence event (Yu et al., 2012). However carers would like to have minimal input in managing the system for example cleaning and replacing sensors. Moisture sensors that are placed into a pad for which incontinent events are alerted via text messaging to the carer were reported to be expensive. Also the carers who changed the patient had to clean the sensors and replace it into the new pad (Wai et al., 2008). A sensor based solution that include non-wired sensors, small sensor size (thin as possible like RFID's), sensor reuse (reusability creates more burden for carers to clean and return sensors at every change, disposable is highly desirable, low cost, safety (carers requested that RF signals should conform to standards, and equipment should not harm patients in case of malfunction or errors because the sensor unit is attached to the diaper that is worn by the patient at all times (Biswas, 2008). Wireless alarm solutions should provide large coverage area for alarm forwarding, flexibility to choose signalling methods (mobile phone text messaging or alarms) and the possibility to poll systems to check on status. Sensors should be thin and flexible and have robust measuring abilities (Biswas, 2008). Ideally a sensor system should involved minimum amount of work from the carers or that the system should be simple enough so that it does not cause a demand on the carers already busy work schedule. This therefore draws to the idea that acceptability of the system and practical compatibility by the carer is so important in order to create an incontinent management system that work successfully within the care home environment (Wai et al 2010). The information on Table 5.3 shows a list of published incontinent detection system, some of which have been trialled. Most of the systems use in pad sensors to detect urine and alerts are sent through wireless or radio frequency transmission. In order to design a suitable humidity detection system it is important to be aware of the existing designs that have been published. High rates of false detections rate within the clinical care home setting might results in distrust by the carers towards using such a system. Early and reliable methods for detecting incontinence could result in a reduction of carer workload (Schneider et al., 2011).

5.3 Conclusions

In order to better understand the microclimate between the seat and the person, and to appreciate the factors involved (human skin physiology, humidity's at the seat –person interface, measurement limits of the sensors and the perceived usefulness of a sensor based detection solution) it is important to appreciate the influence of humidity measurement and how they interact to affect the user. It is important that the study may be used to translate into a working prototype that could be used to study its usefulness within a care home setting to detect incontinence in dementia residents. The study showed that carers of incontinent dementia sufferers were interested in using sensor technology in line with their current management protocol as long as they were provided with supporting information. Most carers thought that technology may be a way to alleviate burden of care and to remove the barrier of communication between the carer and resident. The neurological nature of dementia sufferers may generally inhibit the recognition of an incontinence episode and it was in this light that carers thought sensor technology may help manage skin integrity. Sensor technology that appropriately identifies incontinence may reduce levels of emotional stress because carers would know when it is appropriate to change the resident. However one important issue highlighted was the reliability and accuracy of the sensor system. The industrial humidity sensors used in the authors study was carefully investigated to fathom it's usage within the care home setting. It was interesting to point out that the humidity sensors used in the authors study consistently tracked the humidity levels of a climatic chamber (traceable to National standard) although they were found to lag the profile. A correction factor may be incorporated to correct the value of the reading so that it reads in line with the climatic chamber which is traceable to National Standards. Sensors that are were used for previous testing over a 3 year period showed sign of wear through a reduction in accuracy when compared to a set of brand new sensors. However new sensors which were powered did show sign or ageing with one was exposed to high kitchen humidity and consistent exposure to sitting for a duration of 7 months. The sensors did increase in accuracy after being dried using a desiccant.

Table 5.3 : Published incontinence sensor detection systems

Authors and years	Study description
Wait et al., 2008	Event acquisition sends text messages to the carer for every urine episode. Moisture sensors placed in pad. When carers change resident they clean and replace the sensor in a new diaper. A one week trial on one elderly dementia resident: detected incontinence without any false alarms, detection occurred for 50% of the time. Out of 21 manual checks, 14 urinary incontinence episodes involved diapers changed. Sensor detected 7 of these 14 episodes. Expected zero false alarm rates was tested in a mock experiment carried out in a laboratory. For the actual trial the sensitivity of the wetness sensor was deliberately reduced to eliminate the false alarm. False alarms could reduce the practicality of the device and may cause unnecessary burden to carers. Limitations: Factors that affected the detection rate were location of sensors (limited contact of urine to the sensor lowered the detections rate), different types of incontinence pads (the rate of spread of wetness and location of wetness confinement which could be missed by the sensor), sensitivity of sensor, the wireless sensor nodes (may not be placed in the correct location by the carer thus not being within the coverage range to detect a signal and carers performed less manual checks due to relying on the system which should not be done.
Wai et al., (2010)	The sensors used were reusable in nature although this behaved once in an only 'catch or miss' signal which required carers to clean sensors and enduring it is dry before reinserting the sensor in a new diaper. The different levels of wetness mean that carers do not change a diaper if it is not completely soiled however the sensor system would detect this and the carer would have to carry out a sensor replacement procedure in order to reset the sensor. Failure to do so or if the incorrect procedure is carried out, and therefore cause the sensor to not detect the next wetness state or just detect the current wetness state which would be a false alarm. Trial involving 6 to 10 elderly people with dementia in a nursing home. Limitations: incorrect sensor placement, human operating errors and technical limitations. This study found that 'on time checks', after and before checks based on a time difference of 30 minutes between a manual check and an automated check showed that the manual diaper check is not able to manage incontinence by detecting soiled diapers in a timely manner. Although this sensor system is able to do so, it seems to miss half of the occurrences. The sensor replacement procedure was reported to burden on the carers because they had to clean, dry and reinsert the sensor back into a clean diaper. Improper handling (such as surface of sensor not completely dry or even accidental throwing away of the sensor) of the sensors have caused the system to malfunction.
(Biswas et al., 2008).	Incontinence detection system that utilises a reusable sensor placed inside an incontinence pad with details of events sent to an alert system The system could monitor several people at the same time as long as they are in a similar area. Receivers were permanently placed in the chair or a bed. Sensors were non-disposable so they still need to be cleaned and replaced every time. Sensor and transmitter pair were coupled with wireless communication. It provides text messenger and web-based manager. The methodology used a questionnaire and focus groups. The questionnaire study looked at views of carers were investigated on their needs to perform diaper change within a timely manner. There was the need to determine if patients had soiled diapers for long period of time. Two groups A & B responded. Group A (Singapore) on staff from two nursing homes: 44 responders Group B (Taiwan) staff from a single elderly care institution. (average age 87yrs): 30 responders (7 with nursing licence, 23 were trained carers). The results of Group A showed that 42 agreed that a sensor detection system would save time on detection and cut down on unnecessary checks. Two disagreed because they felt that following a schedule of 3-4 hours of routine checks is good. And Group B: 43% felt that they disagree that timely change of diapers was difficult to achieve and about half disagreed that time could be saved by cutting down on unnecessary checks. 27 of the 30 homes check every 2 hours.

(Yu et al., 2012)	One sensor inserted into a specially designed pad for elderly. The system aimed to alert carer of an incontinence event and records the urine output and transmits it. It was tested on 32 older people living in nursing home. The voiding patterns were monitored over 72 hours and urine outputs were recorded. Data collected was used to develop individualised care plans. Reassessment was carried out after 2 weeks and then at 5 weeks. Also there was successful voiding events into the toilet (p=0.016) and a reduced volume of urine into continence pads (p=0.013). Having a telemonitoring system for UI management was associated with successful assistance with using the toilet and fewer episodes of UI. Carers had increased awareness about the UI needs and increased appropriate contact times were made with older people.There was a significant increase in the number of times carers had to assist the older person to use the toilet (p<0.001).
Nilson and Gullikson (2011)	A passive UHF RFID tag was inserted into an incontinence pad and the communication efficiency was studied. Active RFID's were found to reduce risk of communication although they are costly. Passive UHF RFID sensors can fulfil the specifications needed for incontinence detection as well as cost specification targeted by manufacturers. The system was able to detect two situations. It was found that when the pad was fully saturated a signalling failure occurred or no RFID response is created. However no action was required when RFID responses were received. Limitations: the antenna's of the RFID tag cannot be near or embedded in water because it will get severely affected by waters high dialectic constant. Antennas may also experience high ohmic losses if introduced to urine that has high salt levels. Antenna's near any liquid could detune it's resonance frequency and introduce ohmic losses to the antenna. Different RFID tags have different levels of sensitivities although generally according to the experiment in this study (tested two types of RFID's : UPM Rafsec and Alien Tag), an RFID tag located over an area with absorbed urine will not be able to read at distances longer than 0.5meters. Body shielding can also be one cause of signal failure. The human body consists of mostly water and direct contact of the tags with human tissue may interfere with the communication efficiency. This study also showed that the RFID reading range improved when RFID tags were placed further from human tissue (50cm reading range when tags are 2mm from human skin and 275cm reading range when tags are 8mm away from human skin). Adding an RFID inlay and an active radio was suggested to cause an increase in the price of one incontinence pad by over 6% of its unit price.
Schneider et al., 2011	An algorithm was developed for a sensor detection system (placed on top of a mattress and under a bed sheet) which could determine whether the skin has reached a moisture level (from incontinence) which may risk the patient of pressure sores. The differentiation between sweat and an incontinence event was also studied and no similar studies were found on this topic in particular. It was envisaged that by placing a moisture sensors between the bed sheet and mattress, moisture increases could be detected. The level of moisture above a hazardous level could be detected and carers could be notified so that they can clean the patient, change the bed sheets. The wetness sensors (conductive) provided by Linak was connected to a microcontroller (Texas Instruments MSP430) to a PC running LabView 2010. Data was sampled at 13 Hz with a 10-bit ADC. There is a proportional rise of the wetness sensor voltage with moisture level and the maximum voltage output is 2.5V. Trials: Two experiments were carried out. In the first experiment six young healthy individuals slept on a mattress where the sensors were placed underneath the bed sheet and the perspiration rate was measured. The second experiment a sheet was placed over the sensors and 3ml urine simulation solution was applied to the sheet with a pipette. The limitations of this study was that it did not use a real incontinence event and urinary leakage was applied one and the small subjects were not incontinent. The study showed that if very small amounts of liquid was detected then larger amount would also be possible however it was not demonstrated. Multiple wet testing was also not demonstrated. Although it was reported that a high perspiration rate might lead to false detection of an incontinence event.

Tanaka et al., 2009	Self powered urinary incontinence sensors that consist of a disposable urine activated coin battery and a developed wireless transmitter. In order for urinary sensors to be utilised most effectively it has been reported that it needs to be wireless to enable mobility, and self powered or constructed in a way to avoid the periodic replacement of a battery (Tanaka et al., 2009). For a self powered to function it requires an ultra-low power wireless transmitter that operates at a voltage close to 1V.
Fernandes et al., 2011	Investigated a sensor detection system that monitors the leakage of urine from incontinence pads to the surrounding underwear. There have been designs and methods used and researched to monitor and control urine. Most these were reported to be designed for care homes use where sensors are placed inside incontinence pads that are set up using wireless technology.
(Van Den Heuvel et al., 2011).	The sensor detect urine in contact with the underwear although does not collect information from the pad. The device alerts the wearer through a vibration system and not to the carer used more suitable for healthier and mobile individuals.The sensor monitors urine when in contact with the underwear to avoid it seeping from the wet underwear and cloths and to the seat surface. Immediate detection of the temperature effect of overspill may not be discernible on the skin and thus detected by the wearer. The sensors is a pair of conductive material sewn onto the interior leg cuffs of the underwear. A microcontroller, a vibration unit, a coin cell and associated drivers are mounted on a printed circuit board and is called the signalling unit. This is attached to the front of the underwear with studs. The device is normally in asleep more until activated by urine contact which activates a vibration sequence (Van Den Heuvel et al., 2011). The smart underwear was successful in alerting the wearer of an incontinence event most of the time (94%) although false triggering did occur although they were reported to rather have the device be oversensitive than under.
(Mashinchi and Barda, 2011)	The SIM (smart incontinence monitoring) is a wireless system that detects urinary events and in turn alerts carers in a nursing home (Mashinchi and Barda, 2011). It has been reported that current incontinence management dictate intensive care by carers due to delays in attending the resident, heavy workload on carers and discomfort of the resident due to unnecessary frequent checks or delays in changing inco pads The system comprises of a disposable sensing pad, being a standard incontinence pad specially fitted with a sensor, a detachable and re-usable transmitter , a wireless network for managing signals, and software on a central computer for monitoring, analysing and recording continence events and for controlling associated communications to care staff. The algorithm used in this sensor detection system makes recommendations which can prevent a resident being kept in a pad containing urine for more than its maximum capacity with a performance greater than 90%. The author reported that recent work on incontinence detection only discuss wetness detection and not time to change. During a study, the time to change feature of the SIM system showed that the residents don't require frequent checks, helps improve overall cost efficiencies and caring facilities. The time to change facility records the accumulated volume (between 500ml to 700ml)and not urine voiding as multiple events. Multiple event recording is something that may be generated for future research through the use of hybrid algorithms which the company is currently researching.

The sensors were very sensitive to detecting moisture present at different distance. Levels of humidity were recognised according to amounts of moisture introduced which indicates that levels of humidity should be further researched and used to determine detection levels. For example a trigger for the sensor green (dry) 0-40%Relative humidity (RH), orange (damp but not wet) 41-75% RH (normal human seated for 20-40mins is about 50%RH in a room where the temp is 20 °C and 30%RH) and red (wet, so alarm for change) at >75%RH. Sensor encapsulated in a in a water impermeable, vapour permeable material was able to detect changes in humidity in the same way as when it was without any cover. This would work well with reducing the need for cleaning the sensors and possibly preventing the sensor circuit from any water damage. Embedding the sensors in cut out recesses within the foam cushion allows the sensors again to be protected from the direct force of the sitting. The humidity is likely to build up in the space within the recess which might make the detection humidity variations easier for the sensors to determine. Embedding the sensors also creates the perception that the sensors are not there which would be beneficial for dementia sufferers who may be affected by visible detectors. A contoured seat would allow repeatability of measurement.

The questionnaire revealed a high proportion of carers agreeing that sensor technology may benefit their management, as long as it was used in parallel to it to address the following: such as staff shortages, demand on carers (due to the nature of caring for dementia sufferers), reducing undetected urine episodes between checks and reducing expensive referrals. Sensor technology could be part of a long term management plan but it also may have the other more important task of shifting the resident from being incontinent to becoming near of fully continent. Incontinence may not be an independent issue, as behavioural challenges come with it. It was found that behaviour appears to fluctuate in dementia residents and the carers have to continuously ensure that the resident's wellbeing is maintained. This is what mainly causes the carer to feel a burden making management more of a challenge. One area highlighted in this section is the high staff turnover rate in care homes. Frequent change of staff may suggest that residents are not always looked after the same person. Perhaps sensors which when set up would be permanent to the resident and may be able keep track of UI occurrences which could be used as better tool for continuous recording of affected individuals. In the author's study humidity sensors are able to detect differences in humidity between the coccygeal and thighs regions during prolonged periods of sitting (40 minutes). The coccygeal region is always higher than the thigh region irrespective of sex. Sensors encapsulated in bags successfully detected humidity sitting and standing interface profiles. Variations on measurement were also found between thighs and coccyx on different surfaces. The humidity sensors were found to react instantaneously upon a subject sitting as well as standing and this was consistent between the three cycles of this. When the subjects stand the sensors need more than 10 minutes to equilibrate back to the ambient room humidity. With each cycle of sitting the sensors measure the same level of sitting humidity exuded by that person indicating that the sensors are able to detect multiple sitting and standing activities. During the sit and stand activity, sensors are able to detect the changes immediately although require time to stabilise before being able to detect changes in humidity. Little difference was found in male and females in the sit and stand study although longer sitting experiments which was done earlier has addressed the differences. The sensitivity of humidity sensors found would be useful in detecting changes at the seat surface in relation to urinary incontinence. Urine exposed to the ageing skin of a dementia sufferer may cause skin maceration which in turn may lead to pressure sore formation. The lack of feedback from sufferers put increased burden on the carer to know when and what the resident needs. In other words without frequent checking on the resident (may be invasive as pads as skin needs to be checked) the carer may not easily know when the resident may be distressed or uncomfortable due to being incontinent. The hourly checking rule may cause carers to work in a regimented fashion, potentially causing missed detections of urinary incontinence between the checks itself. The resident may be unaware that they need to be changed and it is due to this sensor detection technology may be of benefit to inform carers on the well-being of the resident. Technology used within care homes, mainly consists of the nurse call system to call for help when needed and pressure mats or light sensors to detect movement of residents. Although many carers seem reluctant towards the idea of technology, these pre-existing technologies in the homes may indicate that carers may be more willing to consider the idea for a sensor detection system, provided they are trained on how it works. Although there are currently incontinence detection products on the market (not used by any of the homes investigated) incorporating the ideas of carers for the design and function of a detection system may be appropriate to ensure that they get the full benefit from these devices. It is however necessary to further investigate the use of a working prototype in order to identify where improvements are needed.

5.4 Future work and recommendations

This project aims to develop a non-intrusive and non-human attachment method of detecting incontinence which has been developed through the proof of concept stage (McCarthy et al., 2009; Liu et al., 2011) and had favourable market research. This will incorporate a new method of detecting incontinence and skin humidity using industrial humidity sensors that work from inside a seat and protected within a micro weave cover by detecting the increase in humidity of the skin. This method has an advantage over the intrusive sensors (that fit between skin and nappy) where it does not need to be incorporated within any incontinence pads, nappy or diapers. The discrete sensor may be linked to either PDA or equivalent device using RFID technology, which would not require a direct electrical supply (decreasing risk of short-circuit or need for replacement). Coupled to an alarm or PDA based monitor, the device can become an integral part of "smart" seat cushions, undetectable and unlikely to be affected by sterilising issues. Wireless routers (antennas) may vary in the range that they support. Stronger Wi-Fi routers enable higher speeds allowing connection over greater distances with more reliability. Generally speaking in a home network standard Wi-Fi router (802.11b/g/n) can support a range of up to 150 feet (46m) indoors and 300 feet (92m) outdoors. All the devices used in the setup are all CE marked and therefore from a regulations viewpoint medical regulation does not need to be applied (incontinence sensors are unlikely to be classed as medical devices because a medical device is a product which is used for medical purposes in patients, in diagnosis, therapy or surgery. Therefore the detection of urinary incontinence is not within any of these classifications). In order to remove further problems of attaching sensors to a person, it is hoped that using a modified concept in a less subject dependant deployment might potentially be an area that could achieve successful benefits. Humidity levels between perspiration and urinary incontinence would need to be studied further so that the sensors can categorically detect between damp, wet or soaked instances. For example a trigger for the sensor green (dry) 0-40%Relative humidity (RH), orange (damp but not wet) 41-75% RH (normal human seated for 20-40mins is about 50%RH in a room where the temp is 20 °C and 30%RH) and red (wet, so alarm for change) at >75%RH. There is currently a patent that describes a wired or wireless monitoring incontinence system however this uses a mathematical system to create volume estimators of wetness in millimetre (categorised as damp, wet or soaked; or small, medium or large; or wetness being urinary, faecal, or a mix of faeces and urine; or if the cumulative volume of wetness in the pad is below a minimum threshold amount, between a minimum and a maximum threshold amount or above a maximum threshold amount).

Having a system that is able to determine these differences would be important for addressing the issues of false triggering (Lewis et al., 2012). Sensor detection technology could make a significant contribution to the safety, independence and quality of life of the incontinent residents living in care home if they are able to work according to the needs of carers. Although there are currently incontinence detection products on the market (not used by any of the homes investigated) incorporating the ideas of carers for the design and function of a detection system may be appropriate to ensure that they get the full benefit from these devices. In terms of a design of a system sensors that are wireless, protected and easily embedded in a seat of bed surface would allow for smooth transitions of moving residents from beds to chairs or wheelchairs without having to worry about damaging the sensors. Therefore carers will not have to concentrate on multiply transferring sensors or any receivers with the patient as this would add to the undesirable departure of the normal care duty. Any deployment of receivers should be permanently attached to a room, chairs or beds. Sensors that are placed in vapour permeable microweave materials for protection from UI should be easily removed and washed. Sensors embedded in the mattress or seat (removes the notion of risks to infection control) and may only need to be rewashed after long period of time. The washing and reposition of sensors can then be carried out in batched scheduled at convenient times.

The set-up of the system means that the sensors become an integral part of the seat, and is not detectable to the person sitting on it and unlikely to be affected by sterilising issues. The combination of three available technologies (humidity sensor, seat cover material and a contoured seat) is the basis for this research development (Appendix 4a). With a simpler more reliable system made available (especially embedded in the seat or mattresses) these items could be additionally marketed to for use with dementia residents in care home or in the NHS for general ward use. There have been many patents that have covered the idea although further analysis and testing with proper construction of an actual system needs to be carried out so that the patent potential may be investigated (Table 5.4 and Appendix 4b).

Table 5.4: Existing patents for moisture detection

Patent	Study description
Incontinence pad detection patents:	
US 6,603,403 B2 (Jeutter et al., 2003) : Remote,wetness signalling system.	This describes a monitoring method utilising a sensors that may be employed in an incontinence pad. The detection system is able to indicate a change in state from no urine to the presence of it. The monitoring system includes an interrogator (located at operative proximity to the incontinence pad) configured to provide input energy with an input frequency to the sensor. A transponder may generate information when there is urine present. The system uses RFID and wireless technology.
US 6,160,198 (Roe et al., 2000): Disposable article having a discontinuous responsive system	This describes a responsive system which uses sensors embedded in an incontinence pad, to detect a urinary (bodily waste) input. It is a disposable article and the sensor detects an input while an actuator performs the responsive function. The system is responsive to the maximum threshold limit of urine, instead of increasing quantities of urine. The sensor used is not a humidity sensor (please see the last 4 sentences under column 10, reading through to the top of 11).
Water impermeable and vapour permeable substrates	
US 5,948 (Crawley et al., 1998): Non-slip, water proof, water vapour permeable fabric	This describes a non-slip, waterproof and vapour permeable film made from Polytetrafluoroethylene (PTFE) (CW. L Gore and associates) which is stuck with a hydrophilic adhesive onto a layer of stretch fabric. It's application includes medical protective clothing, surgical drapes, liners for orthotic braces and nursing pads (page 4, 2nd paragraph). It can be in direct contact with skin.
US 6,6655,735 B1 (Learning, 2003): Water proof, breathable odour resistant seat cover	This cover is liquid impermeable to protect seat and gas permeable to facilitate evaporation of any moisture such as sweat from the body. The nature of the cover being hydrophobic and non-absorbent (machine washable) means that it prevents odours (eliminates moisture retained in the material to reduce the growth of microorganisms). The material may be treated with an anti-microbial agent.
Assembly of humidity sensors in vehicle seating	
US 2012/0319439 A1 (Lofty, 2012): Climate controlled seating assembly with humidity sensor.	This describes a thermal module comprising of thermoelectric device (Peltier circuit) and a humidity sensor that may detect water, humidity, or condensation on or near the sensor. The sensors appear to be configured in an arrangement in the foam seat. They are not embedded or protected directly by any material.
US 6,818, 842 (Gray, 2004): Seat foam humidity compensation for weight detection	A pressure sensor that is placed under a foam seat is used to detect the weight of an occupant. However a humidity sensor is placed adjacent to it to compensate for the pressure sensor. No sign of embedding or protective materials.

Key: Further work into the construction of the device may include exploring the idea of patenting the device.

6 References

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7 Appendices

Appendix 1 (Chapter 2: Care home study)

a) Crib sheet

b) Questionnaire

c) Information sheet and participant guidelines

d) Table by Barlett, Kotrlik and Higgins (2001)

Appendix 2 (Chapter 3: Sensor study)

a) Saturation pressure table

b) Psychometric chart

c) Calibration certificates (humidity and temperature)

d) Calculations for actual sensor output

e) Room environment recordings

Appendix 3 (Chapter 4: Sitting study)

a) Written informed consent

b) Ethics approval

c) Description of participants

Appendix 4 (Chapter 5: General thesis discussion)

a) Design of a prototype

b) List of patents from literature.

Appendix 5 (Publications)

‘Crib Sheet’

Actions

1. Call numbers on your spreadsheet
2. Explain that you are carrying research for a UK based University. Ask to speak to someone involved in the care and or management of patient suffering from dementia.
3. Once Through always ask for their name and role
4. Always thank

Introduction

Hello my name is Nadia; I am carrying out research to help with the progress of an innovation that is being developed at Glamorgan University.

The innovation is intended to help alert carers who are looking after patients with Dementia/Alzheimer’s who are unable to communicate and or maybe unaware that they have suffered an incontinence event. The innovation can be used through the day and can also be used at night.

Our initial market research indicates that something like this could be of use. I have a couple of questions, which I would be very grateful if you could help with.

Always exit with a thank you

1. How big a problem is incontinence management in the home that you work in?

2. How is the situation currently managed?

3. Would a simple detection device that can be placed on patients clothing and or bed that is able to detect incontinence be useful in the management of patients

4. If yes, how should the device alert the carer number options are under consideration such as the ability to generate a signal to the carers mobile for instance? What would in you view be the ideal means?

5. If no, can I ask why you feel such a device is not of benefit?

6. If interested, would you be able to help the university trial the device?

Date:
Organisation:
Telephone Number:
Person Spoke to:
Role (and contact detail if different):
How big a problem is incontinence management in the home that you work in?
How is the situation currently managed?
Would a simple detection device that can be placed on patients clothing and or bed that is able to detect incontinence be useful in the management of patients
If yes, how should the device alert the carer number options are under consideration such as the ability to generate a signal to the carers mobile for instance? What would in you view be the ideal means?
If no, can I ask why you feel such a device is not of benefit?
If interested, would you be able to help the university trial the device?

Study of the experience of carers in the management of dementia patients with incontinence: **Is there a need for sensor technology?**

Faculty of Health, Sport and Science

University of Glamorgan

Background:

Urinary incontinence (UI) is usually managed manually in care homes through routine checks and toileting. The application of a technological solution to monitoring such as an alerting device may benefit care home management.

Aims:

1. To examine current methods of managing UI in care home residents with dementia
2. To obtain carers' views regarding the use of alerting devices to detect UI episodes.
3. To determine the usefulness of monitoring humidity and temperature changes at the skin surface in relation to UI.
4. To inform the design of any monitoring device.

This questionnaire has 3 sections. Please follow the instructions in each section as appropriate:

- ***Section A (Background)***
- ***Section B (Management) and***
- ***Section C (Product design)***

Please Note: This questionnaire will require information on numbers of residents with dementia and incontinence. When answering about your care home, please be as accurate a possible.

Information for consent

- Completing and returning the questionnaire implies consent to participate in this study and your anonymity will be strictly adhered to.

- All information which is collected about your care home during the course of the study will be kept strictly confidential, will not be used for other studies. Any information you supply will have your name removed so that you cannot be recognised; however the care home can be identified. This is to allow issues relating to misconduct or malpractice to be communicated back to the care home if such information is declared in the questionnaire.

- It is likely that information gained in this study will be published or otherwise disseminated in academic articles and reports. Please note, this information **WILL NOT** contain any information which can identify you or your care home.

- This information will be used only for the purpose(s) set out in these notes and your consent is conditional on the University of Glamorgan complying with its duties and obligations under the Data Protection Act 1998.

Thank you

Researcher Contact Details:
Nadia R. Nair, Faculty of Health Sports and Science, University of Glamorgan.
Pontypridd CF37 1DL Wales UK.
Tel: **01443 482347/07525789335** • Email: **nnair@glam.ac.uk**

Section A: Background information

Information on carer and residents

a. Care home contact details:

Address:

Telephone:

b. What is your allocated job role in the care home? *(Please tick)*

- [ ] Manager
- [ ] Owner
- [ ] Carer
- [ ] Nurse
- [ ] Other *(please specify)*:

c. How many years have you worked in care homes? *(Please round up to the nearest year)*

- [ ] Under 5
- [ ] 6-10
- [ ] 11-15
- [ ] 16-20
- [ ] 21-25
- [ ] 26-30
- [ ] Over 31

d. How many years have you worked in ***this*** care home? *(Please round up to the nearest year)*

- [ ] Under 5
- [ ] 6-10
- [ ] 11-15
- [ ] 16-20
- [ ] 21-25
- [ ] 26-30
- [ ] Over 31

e. What type of care home do you work in at present?

- [ ] Residential
- [ ] Nursing
- [ ] Other (please specify):

f. How many rooms are there within your home?

g. How many residents are currently in your home in total? *(Please specify number)*

Part-time residents ☐ Full-time residents ☐

Additional comments:

....

....

h. How many residents currently: *(Please specify number)*

Have dementia ☐ and also suffer from incontinence ☐

i. In your experience, do residents with dementia who are incontinent ever return to near or full continence?

☐ Yes, occasionally ☐ Yes, frequently ☐ No, never

Please comment if you wish:

....

....

....

....

j. According to your care home policy, how soon after being newly admitted to a care home would a formal assessment on a dementia resident's continence status be performed?

☐ Within a week ☐ Within a month ☐ Within 3 months

☐ Only performed if deemed necessary ☐ Is only performed following incontinence episodes.

k. What factors might prevent someone being assessed within the usual time frame above?

....

....

....

Section B: Management

Care Management for Urinary incontinence

a. How often are residents with dementia who are also incontinent, toileted during:
(Please specify using average numbers)

The day? ☐ The night? ☐

Additional comments: ....

....

b. How many residents with dementia currently have urinary incontinence:
(Please specify the actual number of residents)

Use pads? ☐ Have indwelling catheters? ☐

c. How many incontinence pads are **allocated** per resident with dementia per day? *(Please specify actual number)*

☐

d. In general how many incontinence pads are **used** per resident with dementia in a day?
(Please specify either an actual number or range)

☐

e. On average how often do the incontinence pads of residents with dementia get checked during the:
(Please tick where appropriate)

Day time? ☐ Less than 3 ☐ 3-4 ☐ More than 4

Night time? ☐ Less than 3 ☐ 3-4 ☐ More than 4

f. Would you change incontinence pads if they are: *(Please tick all that apply)*

☐ Mostly dry ☐ Damp ☐ Wet ☐ Saturated

g. Estimate for each resident the number of incontinence pads a week that are not fully used when changed? *(Please specify the estimated number)*

☐ Less than 3 ☐ 3-4 ☐ More than 4

Additional comments:

....

....

....

h. Generally what proportion of residents with dementia also suffers from skin irritation which is probably due to the pads and/or its contents?

☐ Less than 30% ☐ 30-60% ☐ More than 60%

i. Generally, how often do residents with dementia who are incontinent also develop pressure sores?

☐ Never ☐ Rarely ☐ Occasionally ☐ Frequently

j. How are these sores usually managed? *(Please tick all that apply)*

☐ Referred to General Practitioner ☐ Treated by Care home

☐ Referred to Specialist Nurse ☐ Referred to Hospital

☐ Other *(Please specify):*

k. How do the majority of residents with dementia usually react when prompted for toileting at night?

☐ Very resistant ☐ Resistant but manageable ☐ No problems at all

l. Do you observe or make casual inquiries on residents with dementia between routine checks? If so how often? *(Please tick one option)*

☐ Never ☐ Rarely ☐ Occasionally ☐ Frequently

m. How are you alerted regarding an incontinence event between routine checks? *(Please tick all that apply)*

- [ ] By observation on passing the resident
- [ ] Resident notifying carer
- [ ] Do not usually find out until the next routine check
- [ ] Other (Please specify):

Carer Perspective

Please answer the following question in relation to your role as a carer of residents with dementia who are incontinent.

What would you consider your most time consuming tasks associated with managing residents with dementia? *(Please complete the table below)*

Management of	**Please rate the following jobs from 1-4. Where '1' is least challenging and '4' is most challenging.**	
	Rating	**Comment** *(if you wish)*
Feeding		
Behaviour		
Incontinence		
Personal Care		

Management Process

Do you audit the incontinence care in your home? *(If yes please explain how you do that below)*

☐ Yes ☐ No

In the next section we would like to investigate your ideas on what you think a sensor/ detection system to monitor incontinence should be designed to be. The list on page 9 which we request you to rate, contains current ideas that could be used to design a detection system. Please feel free to comment if you wish.

Section C: Product Design: Sensors for informing carers about incontinence episodes.

Product Attributes

a. Please score on the next table, which of the following factors you consider important in such a device (Score 1-5 : where ‘1’=Very important and ‘5’=Not important). *Any comments and recommendations are welcome.*

Device Attributes	Score 1 - 5	Comments and Recommendations
Location of sensors		
1. Sensors embedded in a mattress or seat (under sheets/covering): residents do not see or feel them.		
2. Sensors embedded in clothing: residents do not see or feel them.		
Communication of sensors		
1. Sensors that communicate wirelessly		
2. Sensors that communicate using wires		
Alerting system (Remotely)		
1. Sensors that communicate with carers via a mobile device		
2. Sensors that communicate with a central computer unit		
Alerting system (at residents bedside/location)		
1. A sensor that has an alarm at the bedside		
2. A device that can alert carers discreetly without alarms (eg, lights)		
Design of sensors		
1. Small sensors the size and weight of a 5p coin		
2. A reusable device that can be easily cleaned and used on the same resident.		
3. Single use sensors (sensors are disposed after each use).		
4. A device that can tell the difference between slight and excessive incontinence		
Powering the sensors		
1. Mains powered		
2. Battery powered		

b. Based on the selections and comments that you made in the previous table, do you think that if such a device capable of detecting incontinence existed it could help with your management of the residents with dementia who are incontinent?

☐ Yes ☐ No

If yes or no, please could you state why:

....

....

c. What technology is being used in your home currently?

Technology used	Yes/No	Brand of manufacturer	Brief description of product
Light sensor system			
Pressure Mats			
Nursing Call system for residents			
Incontinence sensing devices			
Other devices to assist general management			

d. Other technology used to assist with management of care including incontinence devices:

....

....

....

....

Thank you for your time in answering this questionnaire.

Dear Care home worker / Manager,

I am writing to invite you/your home to participate in a research project organised through the University of Glamorgan. This project requests you or a designated worker at your care home to complete a questionnaire about your management procedures for incontinence in residents with dementia.

We would also like to hear your views about the role that technology could play in helping with that problem. General information about the project and why you have been chosen can be found below.

We will be phoning your care/residential home sometime in February 2012 to discuss any problems you might have regarding this study and explain anything you do not understand in the invitation below. If you wish to contact us before this point, our details can be found at the end of this letter.

I would be grateful if you could please return the completed questionnaires by: Thursday the 1st of March 2012 using the stamped addressed envelope provided.

Thank you for your time and for considering this request. Your help will enable me to conduct a strong study that will provide valuable results that will hopefully help benefit those in caring for those with urinary incontinence.

Yours sincerely,

Nadia R. Nair

PhD. Research Student

Please read the information sheet below inviting you to participate in this study.

Project Title: Study of the experience of carers in the management of dementia patients with incontinence: is there a need for sensor technology?

Background of study

Urinary incontinence (UI) often influences whether a person can be managed at home or is admitted to a care home, where UI tends to be managed through routine checks and toileting. If return to continence is possible, it can be slowed or prevented by lack of timely detection. Furthermore, changing unused or partially used pads can lead to unnecessary expense and unnecessary service referrals.

Purpose of the study

We aim to examine the current methods of managing incontinence in more detail and to obtain the views of carers regarding better methods of detection to support the current protocols. The outcome would be to inform the design of any future device.

Why have I been invited?

Carers regularly dealing with elderly residents who are incontinent and suffering from dementia are in the best position to inform us on current management methods and if technology can help. There are a number of private care homes that have been invited to participate in this study in Wales and England.

What is required of me if I decide to take part?

You will be required to complete a questionnaire asking you about your views regarding managing the elderly residents suffering from dementia and incontinence. You do not need to disclose your name. We only require the address of your care home. The information we require will be in relation to general capacity and the population in your care home as well as the residents: for instance the total number of residents in your care home, total who have dementia, total who have urinary incontinence and how you currently manage the problem of incontinence.

How do I return the form?

You will be provided with a stamped envelope so that the form can be easily posted back to the researcher.

What will happen to the information?

The information we require does not need any personal information about yourself or the residents. The information about the care home will be used anonymously along with information from other care homes to build a picture of the current problem relating to incontinence in the care home sector and the methods currently used in its management. The data will form part of my PhD and might be used in research publications related to the issue. Data will always be reported without reference to individuals or specific care homes and the data confidentiality will be strictly adhered to.

Completing and returning the questionnaire implies consent for the data provided to be included in this study.

In agreeing to take part in the above Faculty of Health, Sport and Science (University of Glamorgan) research project you are indicating willingness to:

1. Complete a questionnaire asking you about your views on caring for the elderly suffering from dementia and incontinence.

Unforeseen disclosure of harm

We do not pass on any information to anyone, unless we are given information that indicates that there has been or there is potential for the respondent or any other person to be harmed. In that case we are required to pass on the information to the relevant authority (e.g., to the care home manager), however your part in this will be kept confidential.

Data Protection

Please understand that any information you provide will be treated confidentially and that no information that could lead to the identification of any individual will be disclosed in any report based on this project, or verbally to any other party. No identifiable personal data is to be requested.

Withdrawal from study

Your participation is voluntary, furthermore you can choose not to participate in the project without fear of being penalised or disadvantaged in any way.
For specific information or further enquiries about this research please contact the researchers:

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**** Your participation in this study is greatly appreciated and your contribution will be very valuable for the progression of this area of research****

Thank you.

Table 1: Table for Determining Minimum Returned Sample Size for a Given Population Size for Continuous and Categorical Data

Population size	Sample size: Continuous data (margin of error=.03) alpha=.10 t=1.65	alpha=.05 t=1.96	alpha=.01 t=2.58	Categorical data (margin of error=.05) p=.50 t=1.65	p=.50 t=1.96	p=.50 t=2.58
100	46	55	68	74	80	87
200	59	75	102	116	132	154
300	65	85	123	143	169	207
400	69	92	137	162	196	250
500	72	96	147	176	218	286
600	73	100	155	187	235	316
700	75	102	161	196	249	341
800	76	104	166	203	260	363
900	76	105	170	209	270	382
1,000	77	106	173	213	278	399
1,500	79	110	183	230	306	461
2,000	83	112	189	239	323	499
4,000	83	119	198	254	351	570
6,000	83	119	209	259	362	598
8,000	83	119	209	262	367	613
10,000	83	119	209	264	370	623

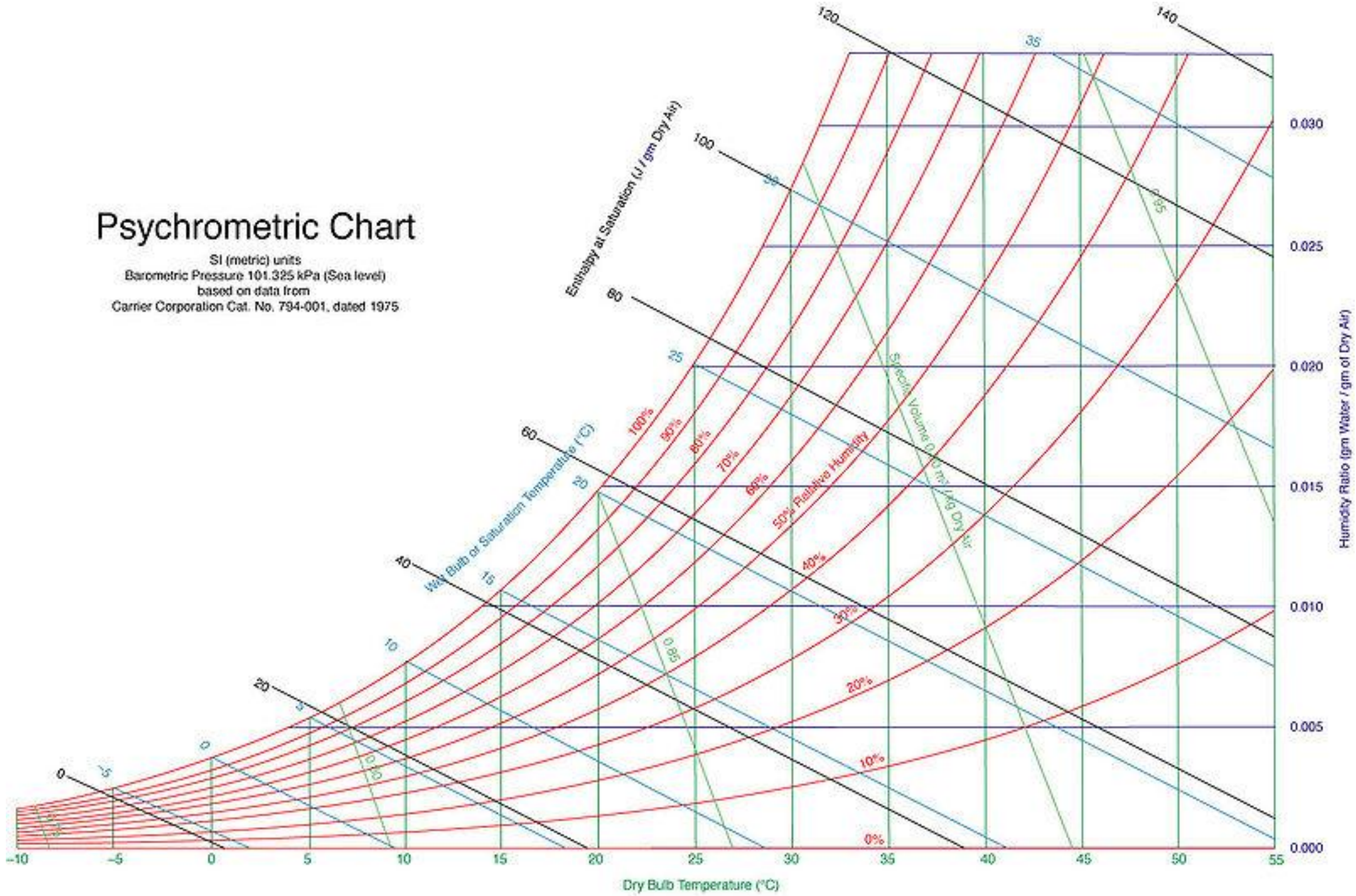
Table developed by Bartlett, Kotrlik, & Higgins published in In Information Technology, Learning, and Performance Journal, Vol. 19, No. 1, Spring 2001' Organizational Research: Determining

Appropriate Sample Size in Survey Research' by Baartlet, Kotrlik, Chadwick and Higgins

Table a: Saturation vapour pressure Data for H_2O

°C	kPa	atm	torr	°C	kPa	atm	torr
0	0.61129	0.006033	4.58	50	12.344	0.121826	92.58
1	0.65716	0.006486	4.92	51	12.97	0.128004	97.28
2	0.70605	0.006968	5.29	52	13.623	0.134449	102.18
3	0.75813	0.007482	5.68	53	14.303	0.141160	107.28
4	0.81359	0.008030	6.10	54	15.012	0.148157	112.59
5	0.8726	0.008612	6.54	55	15.752	0.155460	118.15
6	0.93537	0.009231	7.01	56	16.522	0.163059	123.92
7	1.0021	0.009890	7.51	57	17.324	0.170975	129.94
8	1.073	0.010590	8.04	58	18.159	0.179215	136.20
9	1.1482	0.011332	8.61	59	19.028	0.187792	142.72
10	1.2281	0.012120	9.21	60	19.932	0.196714	149.50
11	1.3129	0.012957	9.84	61	20.873	0.206000	156.56
12	1.4027	0.013844	10.52	62	21.851	0.215653	163.89
13	1.4979	0.014783	11.23	63	22.868	0.225690	171.52
14	1.5988	0.015779	11.99	64	23.925	0.236121	179.45
15	1.7056	0.016833	12.79	65	25.022	0.246948	187.68
16	1.8185	0.017947	13.64	66	26.163	0.258209	196.23
17	1.938	0.019127	14.53	67	27.347	0.269894	205.11
18	2.0644	0.020374	15.48	68	28.576	0.282023	214.3
19	2.1978	0.021691	16.48	69	29.852	0.294616	223.90
20	2.3388	0.023082	17.54	70	31.176	0.307683	233.83
21	2.4877	0.024552	18.65	71	32.549	0.321234	244.13
22	2.6447	0.026101	19.83	72	33.972	0.335278	254.81
23	2.8104	0.027736	21.08	73	35.448	0.349845	265.88
24	2.985	0.029460	22.38	74	36.978	0.364944	277.35
25	3.169	0.031276	23.76	75	38.563	0.380587	289.24
26	3.3629	0.033189	25.22	76	40.205	0.396792	301.56
27	3.567	0.035204	26.75	77	41.905	0.413570	314.31
28	3.7818	0.037323	28.36	78	43.665	0.430940	327.51
29	4.0078	0.039554	30.06	79	45.487	0.448922	341.18
30	4.2455	0.041900	31.84	80	47.373	0.467535	355.32
31	4.4953	0.044365	33.71	81	49.324	0.486790	369.96
32	4.7578	0.046956	35.68	82	51.342	0.506706	385.09
33	5.0335	0.049677	37.75	83	53.428	0.527293	400.74
34	5.3229	0.052533	39.92	84	55.585	0.548581	416.92
35	5.6267	0.055531	42.20	85	57.815	0.570590	433.64
36	5.9453	0.058676	44.59	86	60.119	0.593328	450.93
37	6.2795	0.061974	47.10	87	62.499	0.616817	468.78
38	6.6398	0.065530	49.80	88	64.958	0.641086	487.22
39	6.9969	0.069054	52.48	89	67.496	0.666134	506.26
40	7.3814	0.072849	55.36	90	70.117	0.692001	525.92
41	7.784	0.076822	58.38	91	72.823	0.718707	546.21
42	8.2054	0.080981	61.54	92	75.614	0.746252	567.15
43	8.6463	0.085332	64.85	93	78.494	0.774676	588.75
44	9.1075	0.089884	68.31	94	81.465	0.803997	611.03
45	9.5895	0.094641	71.92	95	84.529	0.834236	634.02
46	10.094	0.099620	75.71	96	87.688	0.865413	657.71
47	10.62	0.104811	79.65	97	90.945	0.897557	682.14
48	11.171	0.110249	83.78	98	94.301	0.930679	707.31
49	11.745	0.115914	88.09	99	97.759	0.964806	733.25

Key: Reference: Handbook of Chemistry and Physics: 73rd Edition (1992-93)



Psychrometric Chart
SI (metric) units
Barometric Pressure 101.325 kPa (Sea level)
based on data from
Carrier Corporation Cat. No. 794-001, dated 1975
Enthalpy at Saturation (J / gm Dry Air)
Wet Bulb or Saturation Temperature (°C)
50% Relative Humidity
Specific Volume 0.90 m³/kg Dry Air
Humidity Ratio (gm Water / gm of Dry Air)
Dry Bulb Temperature (°C)

CERTIFICATE NO: 6557

CERTIFICATE OF CALIBRATION

CUSTOMER: University Of Glamorgan

ADDRESS: Pontypridd
Mid Glamorgan
CF37 1DL

EQUIPMENT TESTED: FS990-40HV

SERIAL NUMBER: 1705

FUNCTION CALIBRATED: HUMIDITY

RANGE: 11% to 90%

INSTRUMENTS USED:

NOVISINA POTS, S/NO`S. 0806104, 0910025, 0710020. 0709214

CALIBRATION COMPLETION DATE: 4th June 2010

ALL INSTRUMENTS USED ARE TRACEABLE TO UKAS CERTIFICATION

RECORDER INDICATIO	**CONTROLLER INDICATIO**	**TEST INST. INDICATION**
	11.2%	**11.3%**
	56.6%	**54.4%**
	75.6%	**75.5%**
	91.3%	**90.1%**

Laboratory temperature at time of test - 22ºC
Laboratory humidity level at time of test - 50%RH

SIGNED: **(Test Engineer)**
DATE: 9-6-10 **DE 041/B**

CERTIFICATE NO: 6556

CERTIFICATE OF CALIBRATION

CUSTOMER: University Of Glamorgan

ADDRESS: Pontypridd
Mid Glamorgan
CF37 1DL

EQUIPMENT TESTED: FS990-40HV

SERIAL NUMBER: 1705

FUNCTION CALIBRATED: TEMPERATURE

RANGE: -40°C to +140°C

INSTRUMENTS USED:

YOKOGAWA, TYPE 436006, CH4, S/NO. 12a331183

CALIBRATION COMPLETION DATE: 4th June 2010

ALL INSTRUMENTS USED ARE TRACEABLE TO UKAS CERTIFICATION

RECORDER INDICATIOI	CONTROLLER INDICATIOI	TEST INST. INDICATION
	-39.9°C	-41.5°C
	-20.3°C	-22.4°C
	+139.9°C	+140.6°C
	+19.9°C	+18.0°C

Laboratory temperature at time of test - 22ºC
Laboratory humidity level at time of test - 50%RH

The overall measurement level at time of test is ± 0.35ºC

SIGNED: **(Test Engineer)**
DATE: 9-6-10 **DE 041/B**

Appendix 2d, Table A: Epoch points collected at the most stable parts of each 5 %RH incremental level through the humidity profile.

	30.0			35.0			40.0			45.0			50.0		
	B	A	e	B	A		B	A	e	B	A	e	B	A	e
1	29.6	38.6	8.9	34.8	37.7	2.9	39.6	40.6	1.0	42.8	43.1	0.3	48.0	50.0	2.0
2	29.4	36.5	7.1	34.9	36.9	2.0	39.5	41.2	1.7	43.0	46.8	3.8	48.2	49.4	1.2
3	29.6	37.7	8.1	34.8	39.5	4.7	39.5	43.8	4.4	42.9	45.4	2.5	48.2	48.7	0.6
4	29.5	38.4	9.0	34.7	39.2	4.5	39.5	39.9	0.3	42.9	46.2	3.3	48.1	49.9	1.8
5	29.1	38.6	9.5	34.8	39.9	5.0	39.4	40.5	1.1	42.8	47.9	5.1	48.0	51.9	3.8
6	29.7	39.0	9.4	34.8	39.5	4.7	39.4	38.7	0.7	43.0	44.9	2.0	48.2	47.0	1.2
7	29.6	36.2	6.6	34.8	40.4	5.6	39.4	43.3	4.0	42.7	47.7	5.0	48.3	50.5	2.2
8	29.8	36.4	6.7	34.8	41.1	6.3	39.5	43.0	3.5	43.0	45.4	2.4	48.2	50.3	2.1
9	29.7	36.7	6.9	34.8	40.3	5.6	39.5	42.2	2.7	43.0	46.6	3.5	48.2	50.3	2.0
10	29.5	38.1	8.6	34.8	41.0	6.3	39.1	44.3	5.2	43.0	45.5	2.5	48.2	49.2	1.0
11	29.5	38.2	8.7	34.7	39.8	5.1	39.6	43.7	4.1	42.5	45.2	2.7	48.2	48.6	0.4
12	29.5	37.9	8.4	34.6	39.4	4.8	39.4	42.8	3.3	43.2	46.6	3.4	48.0	46.6	1.4
13	29.6	37.2	7.6	34.6	40.4	5.7	39.4	43.2	3.8	43.3	45.1	1.8	48.4	49.2	0.8
14	29.7	35.8	6.1	34.8	40.2	5.4	39.5	42.0	2.6	43.1	46.1	3.0	48.2	47.0	1.2
15	29.3	37.7	8.3	34.7	41.4	6.7	39.4	41.5	2.1	42.9	43.5	0.7	48.2	49.5	1.3
16	29.5	36.3	6.7	34.6	40.6	6.0	39.4	42.6	3.2	43.5	45.7	2.2	48.2	48.9	0.7
17	29.7	39.7	10.0	34.6	38.3	3.7	39.5	39.4	0.1	43.4	43.3	0.2	48.1	51.0	2.9
18	29.6	38.0	8.4	34.5	38.9	4.4	39.6	39.0	0.6	43.3	43.9	0.6	48.2	47.4	0.9
19	29.7	38.4	8.7	34.5	39.4	4.9	39.6	41.2	1.6	43.6	46.6	3.1	48.3	45.8	2.5
20	29.7	36.4	6.7	34.5	38.9	4.5	39.5	38.3	1.3	43.5	46.4	3.0	48.2	44.7	3.5
21	29.3	37.0	7.6	34.2	37.8	3.6	39.5	38.5	0.9	43.4	46.9	3.5	48.3	46.0	2.3
Mean	29.6	37.6	8.0	34.7	39.6	4.9	39.5	41.4	2.3	43.1	45.7	2.6	48.2	48.7	1.7
S.D	0.2	1.1	1.1	0.2	1.2	1.1	0.1	1.9	1.5	0.3	1.4	1.4	0.1	1.9	0.9
Min	29.1	35.8	6.1	34.2	36.9	2.0	39.1	38.3	0.1	42.5	43.1	0.2	48.0	44.7	0.4
Max	29.8	39.7	10.0	34.9	41.4	6.7	39.6	44.3	5.2	43.6	47.9	5.1	48.4	51.9	3.8

	55.0			60.0			65.0			70.0		
	B	A		B	A		B	A		B	A	
1	52.6	52.9	0.3	56.9	57.1	0.2	61.2	58.5	2.7	66.2	65.0	1.2
2	53.3	51.1	2.3	56.9	58.7	1.8	60.8	60.3	0.5	66.2	62.8	3.4
3	53.4	53.7	0.3	56.9	58.4	1.5	61.2	60.5	0.7	66.1	64.3	1.9
4	53.3	54.1	0.8	57.0	58.8	1.8	61.1	58.6	2.4	65.9	66.7	0.8
5	52.9	53.1	0.2	57.2	56.2	1.0	61.0	59.5	1.5	65.8	64.6	1.2
6	53.4	52.8	0.6	56.6	57.6	1.0	61.4	60.8	0.6	65.8	65.9	0.1
7	53.5	52.5	1.0	56.9	57.4	0.5	61.1	58.3	2.9	65.6	65.0	0.6
8	53.7	52.4	1.3	56.8	55.9	0.9	61.2	60.2	1.0	65.8	64.3	1.4
9	53.1	52.3	0.7	56.9	58.0	1.1	61.2	59.8	1.4	65.8	64.0	1.7
10	53.5	53.1	0.5	56.8	58.2	1.5	61.2	59.2	2.0	65.7	65.2	0.6
11	53.3	53.5	0.2	56.9	59.1	2.2	61.0	59.1	2.0	65.8	64.5	1.3
12	53.6	52.1	1.5	57.0	59.9	2.9	61.2	64.2	3.0	65.9	64.0	1.8
13	53.4	53.5	0.1	56.9	56.4	0.5	61.2	59.8	1.4	65.4	63.7	1.7
14	53.5	52.4	1.1	57.1	58.5	1.4	61.1	62.7	1.6	65.8	63.0	2.8
15	53.4	52.8	0.5	57.0	59.1	2.1	61.1	60.8	0.4	65.8	62.5	3.4
16	53.5	52.1	1.3	56.9	59.6	2.7	61.1	62.7	1.6	65.8	63.4	2.4
17	53.4	51.6	1.7	57.3	58.2	1.0	61.0	62.9	1.9	65.7	64.8	1.0
18	53.3	51.5	1.8	56.6	60.6	4.1	61.1	62.8	1.8	65.8	64.1	1.7
19	53.5	51.5	2.0	56.7	58.5	1.8	61.1	59.7	1.4	65.7	63.5	2.3
20	53.4	51.9	1.6	56.7	60.2	3.6	61.3	59.7	1.6	65.8	66.4	0.6
21	53.4	53.2	0.2	56.6	59.3	2.6	61.0	60.4	0.6	65.9	64.5	1.4
Mean	53.4	52.6	1.0	56.9	58.4	1.7	61.1	60.5	1.6	65.8	64.4	1.6
S.D	0.2	0.8	0.7	0.2	1.3	1.0	0.1	1.7	0.8	0.2	1.1	0.9
Min	52.6	51.1	0.1	56.6	55.9	0.2	60.8	58.3	0.4	65.4	62.5	0.1
Max	53.7	54.1	2.3	57.3	60.6	4.1	61.4	64.2	3.0	66.2	66.7	3.4

	65.0			60.0			55.0			50.0		
	B	A		B	A		B	A		B	A	
1	61.6	62.0	0.5	56.7	59.6	2.9	51.8	55.8	4.0	51.5	48.3	3.2
2	61.6	61.3	0.4	56.7	56.2	0.5	51.8	55.8	4.0	51.4	49.3	2.0
3	61.4	60.9	0.5	56.7	58.5	1.8	52.1	55.0	3.0	51.4	50.4	1.0
4	61.8	62.7	0.9	56.6	59.5	2.9	51.9	57.0	5.1	51.5	49.3	2.2
5	61.8	63.5	1.7	56.6	58.0	1.4	51.6	55.4	3.9	51.6	49.6	2.0
6	61.7	64.0	2.3	56.4	57.7	1.4	52.1	53.6	1.5	51.3	49.9	1.4
7	61.8	65.4	3.6	56.6	60.3	3.7	51.9	54.1	2.2	51.8	48.7	3.0
8	61.9	64.1	2.2	56.3	58.8	2.5	52.1	53.9	1.8	51.8	48.6	3.1
9	61.9	64.3	2.3	56.1	59.1	3.0	52.1	55.0	2.9	51.8	49.1	2.7
10	61.9	65.0	3.1	56.0	59.5	3.6	52.0	54.1	2.1	51.5	49.4	2.1
11	62.1	64.2	2.1	55.9	60.2	4.3	52.3	55.1	2.8	51.5	49.5	2.0
12	61.6	64.3	2.8	55.4	57.2	1.8	52.0	54.6	2.6	51.8	49.5	2.3
13	61.8	64.4	2.6	55.2	59.9	4.7	51.9	54.4	2.5	51.6	50.6	1.0
14	61.8	65.5	3.7	55.9	57.0	1.1	52.1	54.9	2.8	51.7	50.2	1.4
15	61.5	64.7	3.2	55.8	57.0	1.2	52.0	54.4	2.4	51.6	50.9	0.7
16	61.5	62.2	0.7	55.8	57.4	1.6	52.0	53.0	0.9	51.6	48.4	3.1
17	61.6	64.2	2.6	55.9	60.2	4.3	51.9	53.8	1.9	51.7	49.5	2.2
18	61.4	63.2	1.8	56.0	57.8	1.9	52.1	55.0	3.0	51.8	48.7	3.1
19	61.2	62.2	1.0	55.9	56.9	1.0	51.9	54.2	2.3	51.8	48.6	3.2
20	61.4	62.1	0.7	56.0	55.8	0.2	51.7	54.4	2.7	51.8	49.3	2.5
21	61.1	63.5	2.3	56.2	58.0	1.8	52.1	54.0	1.9	51.8	47.9	3.9
Mean	61.6	63.5	2.0	56.1	58.3	2.3	52.0	54.6	2.7	51.6	49.3	2.3
S.D	0.2	1.3	1.1	0.4	1.4	1.3	0.2	0.9	1.0	0.2	0.8	0.9
Min	61.1	60.9	0.4	55.2	55.8	0.2	51.6	53.0	0.9	51.3	47.9	0.7
Max	62.1	65.5	3.7	56.7	60.3	4.7	52.3	57.0	5.1	51.8	50.9	3.9

	45.0			40.0			35.0			30.0		
	B	A		B	A		B	A		B	A	
1	43.7	44.1	0.5	38.0	42.2	4.2	33.1	36.7	3.6	33.4	33.0	0.4
2	43.6	44.2	0.7	38.2	42.2	4.0	33.3	37.4	4.1	33.3	34.1	0.8
3	43.6	44.4	0.8	38.0	42.6	4.6	33.1	38.1	5.0	33.4	34.1	0.7
4	43.5	45.7	2.3	38.3	42.4	4.1	33.2	38.0	4.7	32.9	35.3	2.4
5	43.6	45.7	2.2	38.2	44.0	5.8	33.1	36.4	3.3	33.2	34.7	1.5
6	43.7	45.6	1.9	38.2	42.6	4.4	33.2	38.1	4.9	33.3	35.1	1.7
7	43.3	44.1	0.8	38.4	42.0	3.6	33.0	37.6	4.6	32.6	34.7	2.1
8	43.6	45.7	2.1	38.0	43.3	5.3	33.2	37.8	4.6	33.2	37.1	3.9
9	43.5	45.1	1.6	38.2	41.8	3.7	33.0	37.1	4.2	33.2	37.0	3.8
10	43.7	43.7	0.0	38.3	42.7	4.4	33.0	38.5	5.5	33.3	36.6	3.3
11	43.7	45.2	1.5	38.0	42.5	4.5	33.3	40.0	6.8	33.4	36.4	3.0
12	43.4	45.8	2.4	38.2	42.2	4.0	33.2	38.1	4.9	33.4	37.9	4.5
13	43.5	45.4	1.9	38.1	42.5	4.4	33.0	38.2	5.2	33.3	37.3	4.0
14	43.6	45.5	2.0	38.2	41.3	3.1	33.1	37.8	4.7	32.9	36.4	3.5
15	43.7	44.0	0.3	37.9	39.7	1.8	33.1	37.5	4.4	33.3	35.6	2.4
16	43.5	45.4	1.9	38.0	41.5	3.4	33.2	37.1	3.9	33.1	37.1	4.0
17	43.7	46.3	2.6	38.1	42.0	3.8	33.0	35.7	2.7	33.4	36.4	3.0
18	43.5	45.8	2.3	37.4	40.8	3.4	33.0	37.3	4.3	33.3	36.2	2.9
19	43.8	45.2	1.4	38.0	40.8	2.8	32.9	39.3	6.4	33.5	37.3	3.8
20	43.1	45.6	2.4	38.0	42.0	4.0	33.0	36.5	3.6	33.2	35.3	2.1
21	43.3	45.2	1.9	37.8	42.2	4.4	33.1	39.3	6.2	33.4	37.0	3.6
Mean	43.5	45.1	1.6	38.1	42.1	4.0	33.1	37.7	4.6	33.2	35.9	2.7
S.D	0.2	0.7	0.8	0.2	0.9	0.8	0.1	1.0	1.0	0.2	1.3	1.2
Min	43.1	43.7	0.0	37.4	39.7	1.8	32.9	35.7	2.7	32.6	33.0	0.4
Max	43.8	46.3	2.6	38.4	44.0	5.8	33.3	40.0	6.8	33.5	37.9	4.5

Table 1: Record of the dates for experiments and the average room humidities.

Months & Dates	Kitchen											
	Ave RH%	Sd	Min	Max	DewP	Sd	Min	Max	Mix. Ratio	Sd	Min	Max
Month 0 (22nd July to 8th August 2011)	65.5	0.7	65.0	66.9	14.6	0.1	14.6	14.8	10.4	0.1	10.4	10.7
Month 1 (15th to 5th September 2011)	56.6	0.1	56.5	56.7	12.8	0.1	12.7	12.8	9.2	0.1	9.2	9.3
Month 2 (12th September to 3rd oct 2011)	72.3	0.0	72.3	72.3	16.8	0.0	16.8	16.8	11.8	0.2	11.6	12.0
Month 3 (10th to 2nd November 2011)	69.0	0.0	69.0	69.0	17.8	0.0	17.8	17.8	12.8	0.0	12.8	12.9
Month 4 (7th to 28th November 2011)	62.6	0.0	62.6	62.6	16.9	0.0	16.9	16.9	12.1	0.0	12.0	12.1
Month 5 (7th to 19th December 2011)	60.5	0.3	60.4	61.1	13.9	0.1	13.9	14.2	10.1	0.0	10.0	10.1
Month 6 (2nd to 27th January 2012)	61.7	1.0	59.7	62.2	15.0	0.3	14.3	15.3	10.8	0.1	10.8	10.9
Month 7 (14th February to 18th April 2012)	56.7	0.4	56.1	57.2	14.0	0.1	13.8	14.2	10.0	0.2	9.6	10.1

Months & Dates	Room containing seat,wall,drawer and unpowered sensors											
	Ave RH%	Sd	Min	Max	DewP	Sd	Min	Max	Mix. Ratio	Sd	Min	Max
Month 0 (22nd July to 8th August 2011)	64.9	0.9	63.4	65.9	14.8	0.2	14.4	15.0	10.6	0.0	10.5	10.7
Month 1 (15th to 5th September 2011)	60.7	4.8	50.8	62.7	14.8	1.3	12.0	15.3	10.9	0.0	10.9	10.9
Month 2 (12th September to 3rd oct 2011)	69.5	1.1	67.2	70.0	16.9	0.3	16.2	17.0	12.1	0.0	12.1	12.2
Month 3 (10th to 2nd November 2011)	61.5	2.1	59.0	65.5	16.6	0.6	15.7	17.6	11.7	0.2	11.2	11.8
Month 4 (7th to 28th November 2011)	65.6	2.9	60.8	69.9	16.6	0.5	15.8	17.5	11.7	0.2	11.2	11.8
Month 5 (7th to 19th December 2011)	53.6	0.2	53.5	54.1	13.3	0.0	13.2	13.3	9.5	0.0	9.5	9.5
Month 6 (2nd to 27th January 2012)	63.6	0.4	63.2	64.1	15.1	0.1	15.0	15.3	10.7	0.0	10.7	10.7
Month 7 (14th February to 18th April 2012)	58.3	0.2	58.2	58.6	14.1	0.0	14.1	14.2	10.1	0.0	10.0	10.1

Participant's information

Project Title: Monitoring humidity and temperature during sitting: developing a greater understanding of the changes at the interface between seat and sitter.

Background of study

It has been suggested that disabled people develop pressure ulcers because they are unable to react to changes occurring in their skin associated to temperature, humidity and pressure. Work in this laboratory has already indicated that temperature changes and movement relate to comfort and discomfort. We now wish to look at humidity in greater detail.

The aim of this study is to explore the interaction between humidity (and temperature) at the interface between the seat and person sitting, as well as to better understand and develop the application of sensor technology for this purpose.

Purpose of the study

We aim to examine the humidity changes and their characteristics during periods of sitting. The technology used here involves the combination of a tight weave (microweave) material (stops liquid water getting through but allowing water vapour to go through) as a seat cover, under which are a series of sensors to detect humidity and temperature. This study will address the characteristics, limits and range of the sensors and expands on previous work by this research group on the reliability of the sensors.

Why have I been invited?

You are a normal, healthy person. In addition, you do not suffer from any condition that will prevent you sitting down for long periods. We wish to study the changes in humidity and temperature under normal people while they are sitting down. The results from studies using "normal", healthy individuals will help us better understand how healthy people prevent themselves from getting pressure ulcers during longer periods of sitting.

What is required of me if I decide to take part?

You will be required to sit on seats (with sensors embedded in the foam which is underneath a material seat cover) for up to 1 hour at a time. During this time the sensors will measure the relative humidity and temperature just below the seat cover. You will be allowed to take occasional breaks for personal comfort, but we would like you to sit down for the whole period if you can. We will measure your weight and height, and also note your age and sex as these will help in later analysis.

What will happen to the information?

The information will be used to build a picture of the measured changes during sitting between different people. The data will form part of my PhD and might be used in research publications related to the issue. Any information you give us will be anonymised. Any publication will only include analysed data from the group and no reference to any individual will be made.

For specific information or further enquiries about this research please contact the researchers:

Researcher Contact Details:
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**** Your participation in this study is greatly appreciated and your contribution will be very valuable for the progression of this area of research****

Thank you.

High Risk Ethics Approval: Care home study 22nd December 2011

From: Sinfield J (HESAS)
Sent: 22 December 2011 13:55
To: Nair N (HESAS)
Subject: FW: Ethics application documents - Nadia R. Nair (PhD Student, HESAS)

Dear Nadia,

Thanks for your patience and revised application. You've now been approved.

Best wishes, enjoy the holidays, and have a happy new year
Jon

From: Beech I M (HESAS)
Sent: 22 December 2011 12:51
To: Sinfield J (HESAS)
Subject: FW: Ethics application documents - Nadia R. Nair (PhD Student, HESAS)

Hi Jon

The main issue of disclosure of malpractice has been addressed. I'm happy with this one to go through.

Merry Christmas

Ian

Dr Ian Beech
Head of Mental Health Division / Faculty Ethics Champion
Faculty of Health, Sport and Science
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CF37 1DL
United Kingdom
(+44)1443 483052

From: Nair N (HESAS)
Sent: 20 December 2011 15:00
To: Beech I M (HESAS); Sinfield J (HESAS)
Cc: McCarthy P W (HESAS)
Subject: Ethics application documents - Nadia R. Nair (PhD Student, HESAS)

Dear Ian and Jon,

Thank you for considering my application for the care home questionnaire study.
Based on the email sent on the 19th of December 2011: Corrections have been made to the documents (attached) in light of the reviewers comments. Highlighted areas (in yellow) are for your attention only and will be removed when deployed for study.

I hope that the documents are satisfactory.

I look forward to hearing from you.

Thank you again.

Kindest regards, Nadia R. Nair

Low Risk Ethics Approval: Care home study 22nd December 2011

From: Sinfield J (HESAS)
Sent: 21 November 2011 09:33
To: McCarthy P W (HESAS)
Subject: FW: LR - pete mccarthy - care home & sitting
Importance: High

Dear Pete,

Re: Low Risk. Comments from the Chair.

Care Home

Firstly this one cannot be low risk. If malpractice is identified then this will be very serious, and the team would need to state how any such findings would be reported. Also, questions are asked about the continence of people with dementia in care homes without their consent being sought or given. There might be confusion here as one question on the questionnaire asks "how many people have indwelling catheters to manage incontinence?" Indwelling catheters are not used to manage incontinence.

A higher risk must be identified for this research, a full application as it stands. Plus, it might be beneficial for the researcher to consult a continence expert to run the rule over the questionnaire design if it hasn't already.

Sitting

This one is ok. Approved.

Table 1: Eleven healthy participants in the group study (6 males and 5 females)

Subject	Gender	Height (m)	Weight (kg)	BMI (kgm^{-2})	Age (years)
A	F (not used)	1.66	75	27.2	19
B	F	1.62	69	26.3	22
C	F	1.67	78	28	19
H	F	1.63	55	20.7	21
I	F	1.74	68	22.5	21
L	F	1.73	67	22.4	30
	Total arithmetical means for females	1.678	67.4	23.98	22.6
	s.d	0.055408	8.203658	3.040888	4.27785
D	M	1.74	79	26.1	19
E	M	1.89	102	28.6	34
F	M	1.83	76	22.7	21
G	M	1.84	90	26.6	19
J	M	1.69	63	22.1	27
K	M	1.83	95	28.4	21
	Total arithmetical means for males	1.803333	84.16667	25.75	23.5
	s.d	0.073666	14.21853	2.779029	5.924525
	Total means and s.d's for all participants	1.746364	76.54545	24.94545	23.09091
		0.090694	14.30639	2.900815	5.009083

Table 2: Mean and s.d's of participants in the sit and stand study

Subjects	Sexes	Height (m)	Weight (kg)	BMI kgm^{-2}	Age
B	F	1.6	69.0	26.3	22.0
C	F	1.7	78.0	28.0	19.0
H	F	1.6	55.0	20.7	21.0
I	F	1.7	68.0	22.5	21.0
	Total Mean of females	1.7	67.5	24.4	20.8
	s.d	0.1	9.5	3.4	1.3
D	M	1.7	79.0	26.1	19.0
E	M	1.9	102.0	28.6	34.0
F	M	1.8	76.0	22.7	21.0
	Total mean of males	1.8	85.7	25.8	24.7
	s.d	0.1	14.2	3.0	8.1
	Total of mean for m &f	1.7	75.3	25.0	22.4
	s.d	0.1	14.4	3.0	5.2

Appendix 4

a) Design of a prototype

As part of the PhD, the author was given the opportunity to co-supervise an MSc student. The aim of the project was to design a sensor based solution system that incorporated a humidity sensor and wireless technology. The humidity sensors in the prototype design study were based on capacitive measurement technology. As highlighted in this study it currently a very common design for conventional humidity sensors. The principle sensing element here is a film capacitor made from a substrate such as glass or ceramic. The dielectric uses a polymer which absorbs or releases water that is proportional to the relative humidity of the environment. This in effect changes the capacitance of the 'capacitor', which is measured by an electronic circuit in voltages. This information is transmitted to the laptop and data can be recorded in real time into Microsoft Excel. The sensors can be from any manufacturer, however in this study the prototype device incorporated one Sensirion sensor (model: SHT71). This sensor was chosen because it has good long term stability and low power consumption qualities that were needed for a wireless setup.

The sensor was connected to a wireless or ‘WiFly’ unit (model: RN-134, built using roving network technology with a 2.4 GHz connection which is a low powered transmission unit using radio waves to communicate wirelessly to other local area network devices (figure 1) . This ultra-low powered device has the ability to wake up, connect to a wireless network, send data, and return to sleep mode in less than 100 milliseconds, allowing it to run for a long time on two standard batteries. Using only 35mA when awake and 4µA when asleep, the WiFly device with this remarkable power efficiency makes it possible a new class of internet-enabled product. In relation to the radio characteristics, the frequency of the system is between 2402 and 2480MHz with 5MHz channel intervals. The WiFly and sensor were mounted on a microcontroller (MCU) (model: PIC18F4520, from the PIC 18F family) which is able to receive the data from the humidity sensor for every minute and stores data for five days in the format of “HH: MM: SS DD: MM: YYYY TEMP: HUMI “this is translated consecutively as: hours, minutes, seconds, day, month, year, temperature and humidity). The Real Time Clock (RTC model: DS1302) which can count in seconds, minutes, hours as well as the date, month, day of the week, and year with leap-year compensation valid up to 2100. The microcontroller is an 8-bit 80C51 5 V low power microcontroller with 64 KB Flash and 1024 bytes of data RAM.

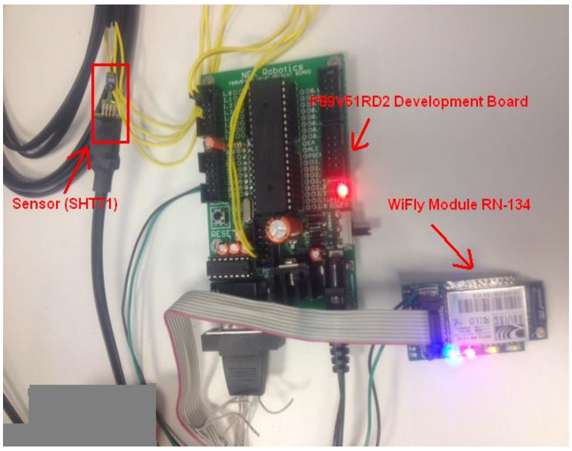


Figure 1: Detection sensor wireless unit

The Graphical user interface was designed using Microsoft Visual Studio (2010) Professional edition programming software (obtained from Advanced Technology, University of South Wales) to support the design application for testing and debugging (Figure 2). Once the GUI was designed a Wi-Fi card can be connected (USB) and activated at the laptop terminal. The simple task of connecting the Wi-Fi card to the WiFly module could then be established (through assigning the IP address of the Laptop). The data collected by the sensor can then be transferred to the laptop’s GUI which can be saved and exported to (according to date) Microsoft Excel for further analysis (Figure 3). The prototype successfully measured the environmental humidity conditions and was recorded on the graphical user interface with accuracies similar to the system used by the author in the main study. The wireless feature incorporated made it possible for the sensor to be more mobile although parts of the system were still wired. Future studies should address a wireless design sensor system where sensors are encapsulated in micro-weave bags and embedding in foam cushions.

Figure 2: Displaying of the Transmitted Data in the GUI from the Sensor.

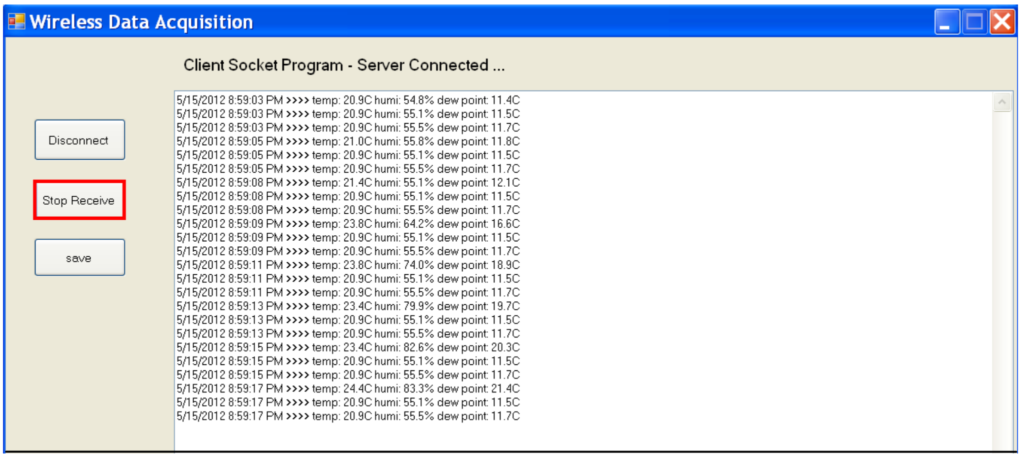
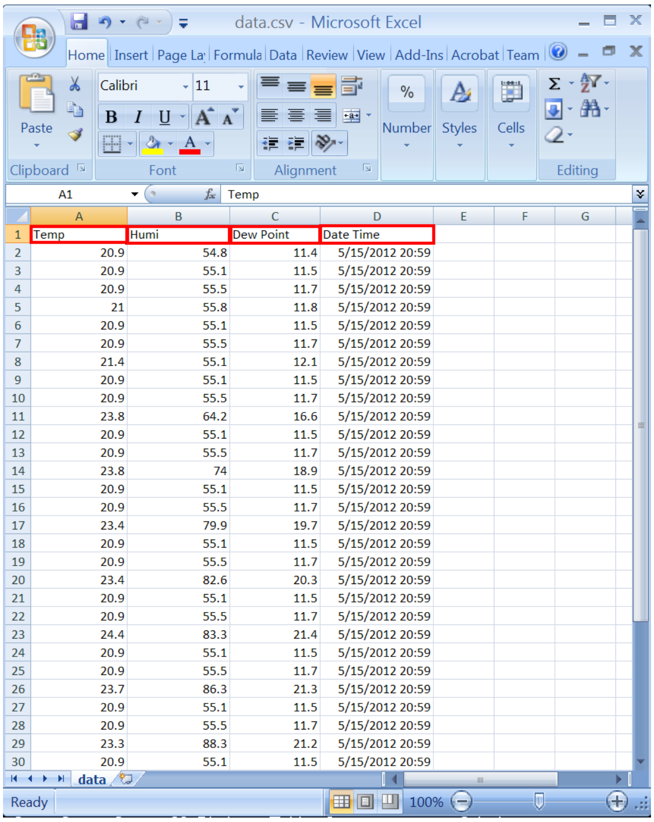


Figure 3: Displaying the stored data in the saved file created.



b. List of patent documents found in literature

No	Publication No.	Publication Date	Title & Abstract
1	**WO 2013185419 A1 (Ding, 2013)**	Dec 19, 2013	**Intelligent incontinence alarm device**
			An intelligent incontinence alarm device comprising an infrared sensor, a process control module, an alarm module and a power supply module. The infrared sensor is opposite to an excretion part of a human body to receive infrared radiation from the excretion. The infrared sensor is connected with the process control module, the alarm and is directly supplied with power. When excrement occurs at the excretion part of the human body, An electric signal generated by the infrared sensor when excretion occurs. This is processed and a signal is sent to the alarm module. The alarm module receives the alarm command and sends remote and/or local alarm information. According to the present invention, faecal and urinary incontinence can be sensed easily and a remote and/or local alarm can be raised by a non-contact type infrared detection method without contact with the human body or the excretion of the human body. The present invention is low in power consumption and high in stability, and can be charged to be reused.
	Summary: This describes a monitoring method utilising a non-contact pyroelectric type infrared sensor (without contact with human body or excrement) that could sense incontinence easily and remotely and an alarm could be raised. When excrement occurs it generates an electrical signal which enters the process control module which in turn raises an alarm.		
	Differences: All modules are connected to one another except the IR sensors which has no contact to the human body or excrement. The device is worn by user on clothes. Alarms can be in the form of L.E.D's or buzzers. The present invention has low power consumption with high stability. It may also be re-charged for re-use. Information may be displayed on mobiles, terminals or PDA's.		
	http://www.google.com/patents/WO2013185419A1?cl=en		

No	Publication No.	Publication Date	Title & Abstract
2	**WO 2013095230 A1** (Carney, Elfström and Bosaeus, 2013)	June 27, 2013	**Method and computer program for monitoring use of an absorbent product**
			The present invention provides a method for monitoring the usage of an absorbent product, such as an incontinence pad or a diaper. The method uses a mobile device to register the movement of the wearer. The movement sensing device evaluates whether the registered movement is indicative of urinary and/or faecal voiding by the wearer, and provides information to the wearer or a caregiver. In this way, the product-wearer or his caregiver can be provided with valuable information related to the use of the product, for example recommendations on when to change the product.
	Summary: This utilises accelerometers that can monitor a person during rest and particularly at night by registering movement. This intervention highlights the fact that people suffering from incontinence are more inclined to void urine and faeces in light sleep phases (increased sleep movement means light sleep phases). Urine and faecal voiding is determined through evaluating registered movements.		
	Differences: Registers movement on individuals to monitor urine and faecal incontinence. No skin contact.		
	http://www.google.com/patents/WO2013095230A1?cl=en		

No	Publication No.	Publication Date	Title & Abstract
3	NZ584897 (A) (Tsai mingliang lawrence; Nguyen-Demary Tinh, 2013)	Jan 25th 2013	**Incontinence device including gasket and bulged cover**
			A body interface device for a urine aspiration system comprises a skin contact pad with gel adhesive for adhering to the skin, and a flexible cover attached to the pad. The skin contact pad includes at least one aperture for admitting urine through the pad into the body interface device. The flexible cover has a bulged form projecting away from the gasket. The flexible cover defines a urine receiving chamber facing towards the gasket, and recess facing away from the chamber for receiving at least a portion of a non-contact liquid sensor. The recess and chamber have a wall portion in common that separates the recess and the chamber. A liquid acquisition material in the chamber receives and transports urine for rapid sensing by the non-contact sensor. An aspiration unit is responsive to the non-contact liquid sensor to apply aspiration suction to the body interface device, upon detection of urine.
	Summary: The device is a well sealed adhesive gasket (intimately placed) containing one or more apertures for urine aspiration into a body interface device. Urine is aspired by a wicking action of a material to enable a liquid sensor. Urine is collected in a chamber (the bulged outer cover) which is connected to the gasket. When urine is discharged it detected by the liquid sensors. This control unit activates the pump to generate a suction through the flexible conduit to draw the liquid into the body interface device. Collected liquid may be measured, visually inspected or sent for testing analysis.		

	Differences: Collects and measures drawn liquid urine detected using non-contact liquid sensors. Device is attached to the skin and upon urine aspiration, a low suction and wicking properties of the device draws urine in to a chamber.
	http://worldwide.espacenet.com/publicationDetails/biblio?DB=EPODOC&II=0&ND=3&adjacent=true&locale=en_EP&FT=D&CC=NZ&NR=584897A&KC=A

No	Publication No.	Publication Date	Title & Abstract
4	DE102011076219 (A1) Elsner, Ulrich, Heinrich, Göran, Lothar, Peter	22/11/2012	**Arrangement for performing contactless detection of moisture in e.g. commercial diaper, has oscillating circuit directly stitched on or into incontinence material that is releasably arranged on or in support material.**
			The oscillating circuit is made from conductive thread like a carrier. The carrier is formed as a continuous structure: a coil and capacitor. The oscillating circuit is stitched on or into an incontinence material (non-woven fabric) that is releasably arranged on or in a support material. The sensor is wirelessly supplied with energy, and capacitively detects moisture.
	Summary: Resonance sensors (metal wires) sewn to an incontinence pad (or non woven fabric) creates an oscillating circuit that communicate (electromagnetic field) wirelessly to an antenna structure that can detect these resonant frequencies. A signal may be triggered only above a certain level of moisture. So the normal moisture levels absorbed by the incontinence pad will not lead to an alarm. The average ingress of moisture in a material is 50ml and this will shift the frequency in circuit.		
	Differences: The contactless property exists between the sensor and the antenna. Sensors are in contact with human skin.		
	http://www.google.com/patents/DE102011076219A1?cl=en		

No	Publication No.	Publication Date	Title & Abstract
5	US2012119912 (A1) Ortega and Sciarra, 2012	17/05/2012	**Active on-patient sensor, method and system**
			A detachable sensor to sense two conditions: pressure from body weight or moisture from incontinence; is applied by adhering to skin or adjacent to the skin. A signal processing circuit, a periodic or continuous transmitter, and a power supply (battery) are associated with a flexible substrate in low profile enabling disposition adjacent the human body. A transmitter antenna is on the substrate. Insulator film between battery contacts and a switch-and-transistor combination are the two power-on techniques. Signals may be transmitted to the bedside or a computer. Other features include: notification signaling; differently responsive antennas; unique identification; low battery detection; anti-collision transmission; patient protocol scheduling; local data transfer from the bedside monitor; and out-of-range transmission detection
	Summary: The sensors is on a flexible printed circuit substance (conductive trace materials) with a signal processing unit, transmitter and power supply (battery) mounted (allows disposition of apparatus adjacent to the human body). Sensors on substrate may be disconnected and reused directly onto skin or in an incontinence pad. Bed side monitor receives signals transmitted from sensors transmitter wirelessly.		
	Differences: Sensors are in contact with skin. Possible cleaning of product needed by carers upon every change.		
	https://www.google.com/patents/US20120119912?dq=US8416088+(B2);+US2012119912+(A1)&hl=en&sa=X&ei=ECZ6U7qeH8-u7Abn5YH4Dg&ved=0CDkQ6AEwAA		

No	Publication No.	Publication Date	Title & Abstract
6	**US 20090149826 A1** Berland, Moberg-Alehammar	Jun 11, 2009	**Absorbent article having a sensor**
			A method for detecting and conveying an alarm signal, when an absorbent article is unfastened or, completely removed from the body of the wearer. Intended to be used in parallel with a method for detecting wetness in the absorbent article and further relates to an integrated detection-and-alarm method for detecting unfastening and/or wetness in an absorbent article. The system includes an absorbent article having at least one absorbent layer, the object to be displaced, such as a fastening system, one or more sensoring devices, one or more transmitting devices, and a remote receiver. For children and adults suffering from incontinence and/or psychological illnesses.
	Summary: Magneto elastic sensors are placed against the skin of the wearer in single use incontinence pads and can detect two situations: when the incontinence pad is unfastened and displace; and an incontinence episode. When there is urine present the sensor detects the load and creates a magnetic flux which can be detected wirelessly.		
	Differences: Uses magnetic fields and sensors are in contact with the skin.		
	https://www.google.com/patents/US20090149826?dq=US2009149826+(A1)&hl=en&sa=X&ei=tTd6U7n3EcTo7AbQjIDgCQ&ved=0CDkQ6AEwAA		

No	Publication No.	Publication Date	Title & Abstract
7	JP2009072396 (A) Yonezawa, Ogawa, Mukai,2009	09/04/2009	**Bioinformation detecting device of bed mattress**
			A bioinformation detecting device includes a pressure sensitive plate**,** a substrate**,** a clamping force variation detecting mechanism arranged between the pressure sensitive plate and the substrate, and a signal combining unit**.** The clamping force variation detecting mechanism includes a first piezoelectric element, a transmission member**,** and a second piezoelectric element in this order. If a clamping force varies in response to vibration acting on a pressure sensitive surface, the transmission member transmits the variation to both the first and second piezoelectric elements which generate signals. The signal combining unit combines the detected signals. Allows reduction of a measurement burden placed on an organism.
	Summary: Pressure sensitive plates utilising piezoelectric technology to detects vibrations. The device is placed on a surface referred to as s 'signal analysing surface'. The device is able to collect information about heart rate, body movement and body posture.		
	Differences: Laboratory environmental set-up with sensing device placed on a surface.		
	http://www.sumobrain.com/patents/jp/Bioinformation-detecting-device-bed-mattress/JP2009072396A.html		

No	Publication No.	Publication Date	Title & Abstract
8	US7053781 (B1) Haire, Bowe and Lakin	30/05/2006	**Apparatus for incontinence detection and notification**
			An apparatus for incontinence detection and notification comprises a notification component, for providing notice that an incontinent event has occurred, and a sensor. The device includes a sensing pad for collecting and retaining fluid resulting from the incontinent event, and a circuit housed within the sensing pad. The circuit has a pair of stainless steel electrodes, which are in electronic communication with the notification component. A closed circuit is created between the electrodes by the fluid resulting from the incontinent event, causing an electronic signal to be communicated to the notification component. The circuit may also include a plurality of connectors placed in electronic communication with the notification component to diagnose a disconnected or poorly connected circuit.
	Summary: A washable reusable multi layer sensing pad that can collect and retain fluid. Embedded is a sensing device comprising a pair of electrodes that creates a closed circuit when in contact with urine. The closed circuit causes an electrical signal to be communicated through a wireless transmitter. Information may be stored and analysed. The sensor and circuit housed in the reusable pad can withstand rigorous heat and chemical cleaning. Pad is in contact with skin.		
	Differences: Cleaning protocol created by the carer or an outside source. Sensors embedded in pad.		
	http://www.google.co.uk/patents/US7053781		

No	Publication No.	Publication Date	Title & Abstract
9	**WO 2010076679 A2** Ales, Long, Tomsovic, Nhan, Weber and Cohen	Jul 8, 2010	**Remote detection systems for absorbent articles**
			Signalling systems indicate the presence of a body fluid in an absorbent article. The various signalling systems do not include any conductive elements contained on the interior of the article. Instead, the changes are monitored from the outer cover of the article. In one embodiment, for instance, conductive zones are formed directly into the outer cover for forming the signalling system. Alternatively, a sensor may be mounted to the outer cover of the article for monitoring changes within the article. The sensor may comprise, for instance, a temperature sensor, a conductivity sensor, an optical sensor, a vibration sensor, a humidity sensor, a material expansion sensor, a chemical sensor, or the like.
	Summary: Describes how two humidity sensors may be used to detect differences of humidity between the interior and exterior of an absorbent pad. Sensors cannot touch liquids and may only be placed through materials of the pad that is breathable and water impermeable. Signals may be emitted for a variety of humidity levels, and there are suggested ways for avoiding false triggering.		
	Differences: Problems arise for humidity triggering levels when sensor are placed in pads of varying breathability properties.		
	http://www.google.com/patents/WO2010076679A3?cl=en		

No	Publication No.	Publication Date	Title & Abstract
10	US 20070024457 A1 Long, Olson, Weber, Ales, Schlaupitz, Wright, Nukuto and Sullivan	Feb 1, 2007	Connection mechanisms in absorbent articles for body fluid signalling devices
			Absorbent articles incorporating a wetness sensor for indicating the presence of body fluid. The absorbent articles include at least two conductive elements that form an open circuit within the article. Each conductive element is connected to a conductive pad member that has sufficient surface area to facilitate connection to a signalling device. Although the absorbent articles is disposable, the signalling

			device is intended to be used with multiple absorbent articles. So a simple and efficient method of connecting the signalling device to pads is possible. For example one pad comprised a conductive loop-type material attached to a conductive hook-type material on the signalling device.
	Summary: Materials of the absorbent article is described so that incontinence detection devices may be housed appropriately. Outer cover materials may be breathable and liquid impermeable constructed from micro porous webs, or polymeric substances. The inner layer of the outer cover can be liquid impermeable and vapour permeable manufactured from thin plastic film or 0.02 polyethylene film. The inner layer prevents waste from wetting the bed or clothing.		
	Differences: The Invacare deep cover is made from polyethylene. Conductive sensing is used.		
	https://www.google.com/patents/US20070024457?dq=US+20070024457+A1&hl=en&sa=X&ei=ewg9VJzxJMrB7AajnYHwDQ&ved=0CB8Q6AEwAA		

No	Publication No.	Publication Date	Title & Abstract
11	CN102496247 (A)	13/06/2012	Remote button and urine-wet integrated alarming system for hospitals
			A remote button and urine-wet integrated alarming system for hospitals. A humidity sensor is fixed on a diaper (through gauze and an adhesive tape) and placed on the patient or infant or on the bed below the buttocks. One output end of the humidity sensor is connected with an input end of a button switch through a conductive wire. This is connected with one input end of an acousto-optic alarming lamp through a conductive wire. A second output of the humidity sensor is connected through conductive wire to the acousto-optic alarm and power supply. Each acousto-optic alarming lamp is arranged on an alarm console inside a medical personnel duty room, is provided with a bed number for patient. Medical personnel can be immediately informed of replacing the wetted diaper of the infant and the patient in time.
	Summary: Conductive sensors are in contact with patient and detect moisture. The alarm system notifies staff through an personal automated system.		
	Differences: Conductive sensors are used. Sensors are connected to alarm through wires.		
	https://www.google.com/patents/CN102496247A?cl=en&dq=CN102496247+(A)&ei=Ygs9VJa-CamM7Aaq2IGgAg		

No	Publication No.	Publication Date	Title & Abstract
12	**WO 2005020864 A1** George	Mar 10, 2005	**Diaper wetness annunciator system** A monitoring system identifies a wet diaper by embedding an disposable passive humidity sensor, and attaching to the outside of the diaper a detachable transmitting module, triggered into transmission by sensor. The transmitting module is sealed and transferable from the wet diaper to a dry one via a coupling arrangement that serves to provide electric power. Uniquely coded data is wirelessly transmitted to a remote receiver. The receiver may be a battery powered portable unit carried by the baby's carer. In a day care centre a multiple function receiver can identify any of several diapers. In hospitals, several receivers are each capable of recognizing and reporting any wet diaper within its range to a central computer. Low cost and long range are achieved by using a detachable and transportable active transmitter that is not discarded with the wet diaper and so can be re-used. False transmissions are prevented by a confirmatory resistance.
	Summary: Sensors are in contact with the person and has a transmitting module attached to the same diaper. The sensor and transmitter communicates wirelessly to a receiver which can report multiple incidences of urine excretion on a central computer.		
	Differences: Low cost disposable passive humidity sensors embedded in diapers.		
	https://www.google.com/patents/WO2005020864A1?cl=en&dq=WO+2005020864+A1&hl=en&sa=X&ei=LQ09VI-uOOKM7Ab-lYCwBQ&ved=0CB8Q6AEwAA		

No	Publication No.	Publication Date	Title & Abstract
13	**US 20120268278 A1** Philippa Mary Lewis, Karen Maree Carey, Alan Michael Cottenden, David Albert Barda, Peter Curran, Don Black,	Oct, 2012	**Incontinence monitoring and assessment**
			A system for monitoring incontinence in one or more subjects comprises display means; input means operable by a user; one or more transmitters, each transmitter being associated with one or more subjects being monitored; the one or more transmitters being configured to transmit signals containing continence-related data for the one or more subjects, wherein the continence-related data has been obtained over time from a continence sensor associated with an absorbent article worn by each respective subject; a receiver unit configured to receive signals from the one or more transmitters; and processing means in communication with at least the receiver unit, the processing means including a display processor configured to process the received signals and communicate display information to the display means for display of a visual representation of continence-related information derived from continence sensors in the absorbent articles worn by the one or more subjects being monitored. The system may include a volume estimator and means for communicating to a carer a 'risk of wetness leakage' based on e.g. an estimated volume of wetness and e.g. a pad type. Pad type may be communicated to the system automatically by way of a pad type indicator associated with the pad and/or pad/sensor combination.
	Summary: A wired or wireless system for monitoring incontinence in one or more subjects, A volume estimator uses a mathematical model to estimate: wetness in millilitres; or categorization such as damp, wet and soaked; or small, medium or large; or wetness being urinary, faecal, or a mix of faeces and urine; or if the cumulative volume of wetness in the pad is below a minimum threshold amount, between a minimum and a maximum threshold amount or above a maximum threshold amount. The pad type indicator uses an identifier circuit on the absorbent article such as e.g. resistance, impedance, capacitance, inductance, a resonant frequency or a carrier frequency associated with the identifier circuit or a potential difference of current value measurable from the identifier circuit.		
	Differences: Sensor is embedded in the pad and physical wetness is detected.		
	https://www.google.com/patents/US20120268278?dq=simavita+pty+ltd+australia&hl=en&sa=X&ei=7F09VKfIFbG07Qa_yYCwDg&ved=0CB0Q6AEwAA		

Appendix 5 (Publications)

Dey, Z.R, Nair, N.R., Shapcott, N. (2013) 'Evaluation of the Force Sensing Application pressure mapping system' Journal of Medical Engineering & Technology- Research carried out at: Rehabilitation Engineering Unit, Morriston Hospital, Swansea, SA6 6NL

Abstract publication for poster presentation:

Nair N.R, McCarthy P.W., Shaw, C., Patz R., Rinaldi F (2011), 'Study of the experience of carers in the management of dementia patients with incontinence: is there a need for sensor technology?' Abstract publication for poster presentation, In: *Incontinence: the engineering challenge, Seminar proceedings 7-8th December 2011,* at the Institution of Mechanical Engineers in Westminster, London.

Nair N.R, McCarthy P.W., Shaw, C., Patz R., Rinaldi F (2011) 'Recognising sensor technology characteristics to measure humidity changes for future urinary incontinence detection' Abstract publication for poster presentation, In: *Annual postgraduate researchers presentation day booklet 6th May 2011, Research office,* University of Glamorgan. (This presentation won first prize: £300). Source:
http://hesas.glam.ac.uk/news/en/2011/may/09/hesas-research-student-wins-prize-annual-postgradu/

Nair N.R., Zietsman B.B., Clegg D.R., Heush A.I. and McCarthy P.W. (2013) 'Using technology to enhance self care'. Abstract publication accepted for the poster presentation, In: College of Medicine's annual conference on 'Self care', at the Royal **College of Obstetricians and Gynaecologists, Regent's Park, London. Source:**
http://ctdru.research.southwales.ac.uk/news/en/2013/jun/24/ctdru-members-nadia-nair-and-bianca-zietsman-prese/

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REVIEW

Evaluation of the Force Sensing Application pressure mapping system

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Abstract

Pressure mapping techniques are used in wheelchair and seating services to assess posture and assist in the prevention and treatment of pressure ulcers. The Force Sensitive Application (FSA) pressure mapping systems in Wales have a high clinical use and frequent calibration is required. This project aimed to assess the performance of the systems and develop a calibration strategy. Testing of the systems was spilt into three stages. The pilot stage compared different calibration techniques (manual, automated and with new software) to determine the optimal calibration frequency. The second stage, longer term, was like the pilot stage with the best calibration method tested over 10 weeks. The third test was a simple before-and-after calibration test, conducted to determine the effect of calibration. It was concluded that the calibration process is essential to maintain the reliability of the mats and it was decided that the systems in Wales should be calibrated every 2 months to provide a more consistent output.

Keywords

Accuracy, calibration, pressure, pressure measurement, reliability

History

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1. Introduction

Pressure ulcers are a major health problem in the UK, causing suffering to people, especially patients with reduced mobility [1–4]. The annual cost of treating ulcers in the UK in 2004 was estimated to be between £1.4–2.1 billion (4% of the NHS budget) [5]. A multitude of extrinsic and intrinsic factors may contribute to the cause of the ulcer or preventing an existing ulcer from recovering. The predominant factor is pressure [2,6–9], as pressure on the skin may be sufficient to impair the local blood supply, which can limit the availability of nutrients and oxygen to the localized tissues leading to a build-up of toxins [2]. Other factors include age, physical condition, poor mobility, posture, reduced sensation, temperature, shear, moisture and poor nutrition [2,9,10].

Pressure mapping techniques can be used to assist pressure ulcer management. Patients who are at risk of suffering from pressure ulcers are placed on a pressure sensing mat, which would be able to measure their interface pressure. This can then be used to determine the corresponding relative pressure distribution from different seating surfaces [11]. Following this it would be possible to make the appropriate clinical selection for a suitable prescription of cushions or mattresses. It has been found that the data produced by pressure mapping can be used to support clinical decisions when assessing and prescribing cushions [10,11]. In addition, the Rehabilitation Engineering Unit in Swansea uses pressure mapping for seating and posture assessments. The Pressure Ulcer Prevention and Intervention Service (PUPIS) at Swansea uses the system for education of the patient and/or carer so that they can see the effect of using pressure-relieving techniques on different support surfaces to help prevent ulcers from forming. It is also used to provide information to help to find the cause of an existing ulcer and to help with the optimum set up of pressure-relieving products, e.g. air-cell cushions. Due to this high clinical demand (204 new referrals, of which 130 have been discharged due to a healed or healing wound in a 1 year period, 2004/2005), the mats need to be consistently reliable and give true readings.

The system used in the five wheelchair and seating centres in Wales is the Force Sensitive Application (FSA, Vistamedical, Winnipeg, Canada). This system comprises of a seat-sized pressure-sensing mat that contains 256 individual piezo-resistive sensors (Figure 1(a)) in a 16×16 grid. The changes in resistance which result from the different pressures on the sensors are interpreted by the interface module which is connected to a laptop running the FSA software. Data representing the sensor pressure can be displayed as colour-coded maps of pressure distribution (Figure 1(b)), 3-dimensional grids and numeric output parameters [12,13].

Long-standing accuracy and stability problems reported by the clinicians who used them in Wales led to the initial organization of simple comparative testing of them, at one time, in one centre. The pressure mats were subjected to a variety of applied pressures individually and all systems produced different results. There was no consistency across the mats, even though they were subjected to the

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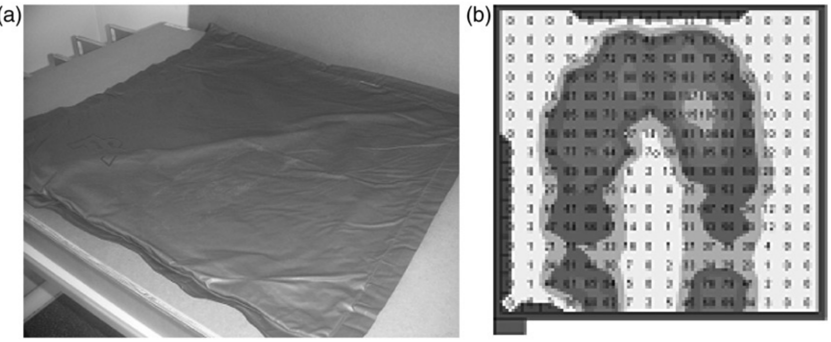


Figure 1. (a) FSA pressure mat; (b) FSA software system display.

same pressure. This raised concerns amongst the clinicians who used the systems regarding the stability, reproducibility and consistency of the FSA system. The outcome of this testing was the realization that further examination of the performance characteristics of the pressure mapping systems was required.

Previous studies [11] on pressure mapping systems have described results from pressure mapping in terms of comparing seating surfaces or clinical judgement on the prescription of cushions; but few have investigated the reliability of the systems.

The study described in this paper set out to determine the consistency of the mats and to formulate a calibration strategy for all the systems in Wales. Vistamedical were actively involved throughout the project.

2. Methods

2.1. Calibration of the mat

Calibration of a pressure mat refers to the process of determining the relation between the output (or response) of the system and the applied pressure. The calibration process attempts to build a time-dependant table to correct for sensor errors. The process also establishes creep and hysteresis values and attempts to correct for these errors. Creep is the tendency for pressure readings to steadily increase under a constant load, it is a function of time. Factors affecting creep can be mat construction, software design, as well as patient movement, creep of muscle tissue and cushion or seating surface. Hysteresis is the energy lost when loading or unloading a sensor.

The pressure mat is calibrated according to the manufacturer's instructions, using a planar loading method. An inflatable air bladder is placed on top of the mat and this whole assembly is placed in a contained wooden box (Figure 2). An air pump with a sphygmomanometer is used to inflate the bag to apply calibrating pressures ranging from 0–200 mmHg. The sphygmomanometer was calibrated at the start of the testing to make sure the pressure readings from it were correct. The FSA software guides the user through the calibration procedure to increasingly apply pressure to the mat in steps of 40 mmHg and down again (although the number of steps can be changed to refine the calibration if needed) to allow compensation for hysteresis error.

Three different methods were used to calibrate the system in this study:

(1) Manual (pumping the air bladder by hand),
(2) Autocalibrator, and
(3) Autocalibrator and new software version (FSA 4.0) with improved hysteresis compensation.

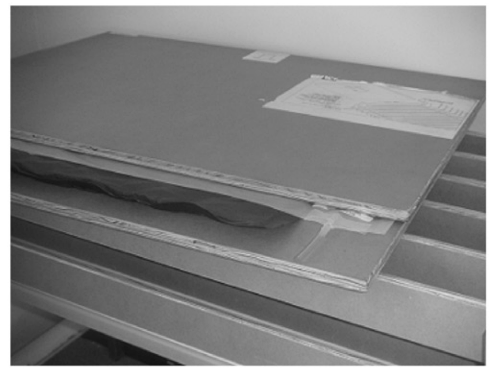


Figure 2. FSA calibration system.

The autocalibrator is an automatic pump which pumps air into the bladder until the selected test pressure is reached and it also releases the pressure. The calibration process is exactly the same, but instead of the user manually pumping up the air bladder, the autocalibrator is used. This eliminates user error when reading the sphygmomanometer. It also regulates the air input and output through the bladder and time at each specified pressure, rather than the variability when manual calibration is used.

The manufacturer of the system states that the calibration procedure should be performed no later than every 50 uses or 3 months for a new mat and thereafter every 200 uses or every 6 months. There was no agreed calibration method or frequency between the five systems in Wales, so a protocol was needed to ensure all were using the systems in the same way.

It is commonly accepted that interface pressure readings increase with increasing applied pressure over time because of the effects of creep [13]. In view of this temporal variation, it is important to investigate whether the output pressure reading 'levels out' after a given period and, if possible, to identify the optimal sitting times for taking definitive pressure measurements [13].

Testing of the mats was conducted at the Rehabilitation Engineering Unit, Morriston Hospital in Swansea. Due to the high clinical use, all the mats in Wales could not be tested, therefore the two systems in Swansea were chosen for the experiment. These were specified as 'black' and 'silver' pressure mapping systems (according to their computer case colour).

Table 1. Results of the pilot study—average pressure data.

		Black mat			Silver mat		
Time		0 min	2 min	4 min	0 min	2 min	4 min
100 mmHg	*p*-value score	0.0015	0.0050	0.0042	0.0010	0.0001	0.0000
	Best calibration method	ACNS	AC	AC	ACNS	AC	AC
	Significance	Sig	Sig	Sig	Sig	Sig	Sig
50 mmHg	*p*-value score	0.0000	0.1376	0.0788	0.0021	0.0259	0.0235
	Best calibration method	ACNS	AC	AC	ACNS	Man	Man
	Significance	Sig	Non-sig	Non-sig	Sig	Sig	Sig

2.2. Pilot study

A pilot study was carried out in order to try to collate data about the performance of the pressure mats.

The two mats were compared over two variables: calibration method (described above) and duration of applied pressure.

Before testing, the mat was calibrated according to the manufacturer's instructions (as described above) and then, for the test, placed in the calibration jig with the pressure increased to 100 mmHg. This pressure was held for a duration of 4 min and three output parameters were recorded during this time at 0, 2 and 4 min. The pressure was then reduced to 50 mmHg and the same output parameters were recorded. The output parameters are:

- Maximum Pressure (Max P) (the highest individual sensor value),
- Average Pressure (Av P) (mean of all sensor values), and
- Standard Deviation (SD) (extent of pressure distribution around the mean).

This procedure was performed once a day for 10 days, with no calibration in between.

This test was then repeated on the mats with the two other calibration procedures (autocalibrator and autocalibrator with new software).

2.3. Longer term testing

To determine the long-term behaviour of the pressure mapping system, a mat was lent to us from the manufacturer. This mat was the same type as used in the testing above, but was isolated from clinical use, as this test would be over a longer period of time.

The system was calibrated using the autocalibration method, as this was found to be the most stable with the lowest Standard Deviation, from the pilot tests above. The mat was then placed in the calibration jig and pressure applied at 100 mmHg and held for 4 min. During this time the output parameters were recorded at 0, 2 and 4 min. The pressure was then reduced to 50 mmHg and, again, applied for 4 min with the output parameters recorded at 0, 2 and 4 min. This procedure was performed once every working day for 10 weeks, with no calibration in between, i.e. 50 uses.

2.4. Effect of calibration testing

To test the effect of the calibration system, a very simple before-and-after comparison was performed on the mat.

After clinical use of the mat (10 uses over 1 month), the mat was placed in the calibration jig and the bladder manually pumped up in steps of 50 mmHg up to 200 mmHg. The three output parameters were recorded instantaneously. The normal calibration procedure with the autocalibrator was then followed. The mat was left in the calibration jig and again the bladder was pumped up in 50 mmHg intervals and results recorded and compared to those before the calibration.

3. Results

When analysing the recordings, only Average Pressure and Standard Deviation data were used. This is because it has been found that Maximum Pressure is sensitive to random experimental errors and is found to be unstable [14]. This parameter only gives one value of the whole mat and is, therefore, not a true representation of what is actually happening throughout the system. Also, due to the experiments using planar loading, the Maximum Pressure should not be a single high peak; therefore, this output parameter was not used to analyse the data.

3.1. Pilot study

To compare the pressure applied to the mat at 100 mmHg and 50 mmHg with the actual pressure output; the ANOVA statistical test was performed. Initially a *t*-test was carried out on the data, but the ANOVA allows more than two groups of data to be analysed. The single factor ANOVA test was performed on the Average Pressure data between the actual pressure output and applied pressure output (100 mmHg or 50 mmHg). This was analysed for all times (0, 2 and 4 min) and all calibration methods. The test determines if there is a significant difference between the means of the three groups. If the significance level (*p*-value) is below 0.05 that means there is a statistically significant difference between calibration methods. Although the test shows there is a significant difference between the groups, it does not show us which group is the best, so the closest mean to the applied pressure was labelled on a table to show which is the best calibration method.

Table 1 shows the ANOVA *p*-value scores, split into four sections: The black and silver mats are shown in columns and the applied pressure values (100 mmHg and 50 mmHg) in rows. The *p*-value scores are shown for each test, with a description if it is significantly different or not (p-value less than 0.05 means significant difference between the three groups). Also the closest mean to the actual pressure reading is noted, i.e. if at 100 mmHg the three readings for the different calibration methods are Man = 98.82, AC = 91.75 and ACNS = 99.737, then the 99.737 is the closest to 100 mmHg, so ACNS is the best.

Table 2. Results of the pilot study—standard deviation data.

	Black			Silver		
Time	0 min	2 min	4 min	0 min	2 min	4 min
100 mmHg						
Best calibration method	ACNS	ACNS	ACNS	ACNS	ACNS	ACNS
Mean	4.6	5.01	5.46	6.61	7.2	7.41
SD	0.81	0.81	0.74	1.22	1.24	1.25
Calibration method	Man	AC	ACNS	Man	AC	ACNS
Best time period	0 min	0 min	0 min	0 min	0 min	0 min
Mean	6.86	6.38	4.6	7.98	7.18	6.61
SD	2.28	1.5	0.81	3.27	1.92	1.22
50 mmHg						
Best calibration method	ACNS	ACNS	ACNS	ACNS	ACNS	ACNS
Mean	3.57	3.8	4	4.28	4.77	5
SD	0.56	0.51	0.48	0.68	0.71	0.7
Calibration method	Man	AC	ACNS	Man	AC	ACNS
Best time period	0 min	0 min	0 min	0 min	0 min	0 min
Mean	4.23	3.85	3.57	5.16	4.53	4.28
SD	1.43	0.72	0.56	1.95	1.01	0.68

The calibration methods: Man, Manual; AC, Autocalibrator; ACNS, Autocalibrator and new software.

Figure 3. Results of the longer term testing (average pressure data) at 100 mmHg with range between 80–120 mmHg.

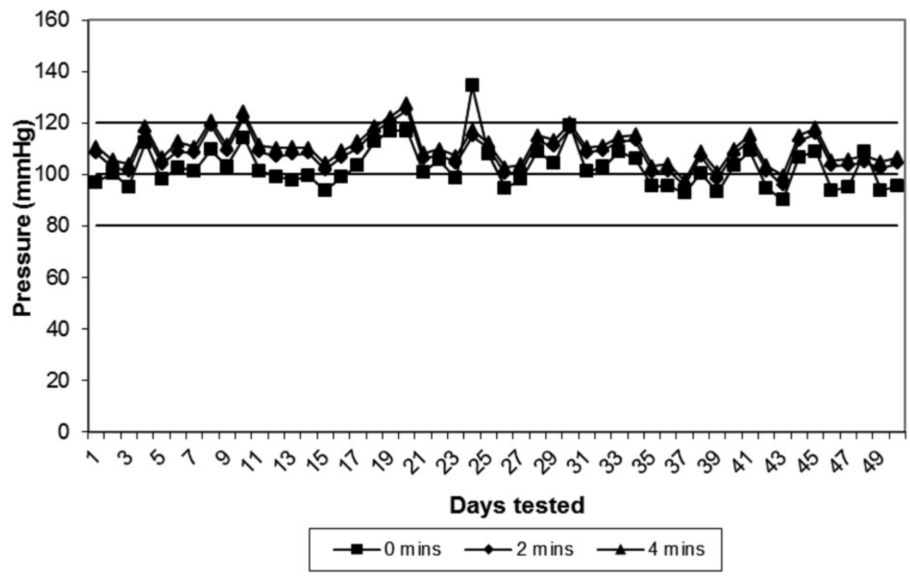
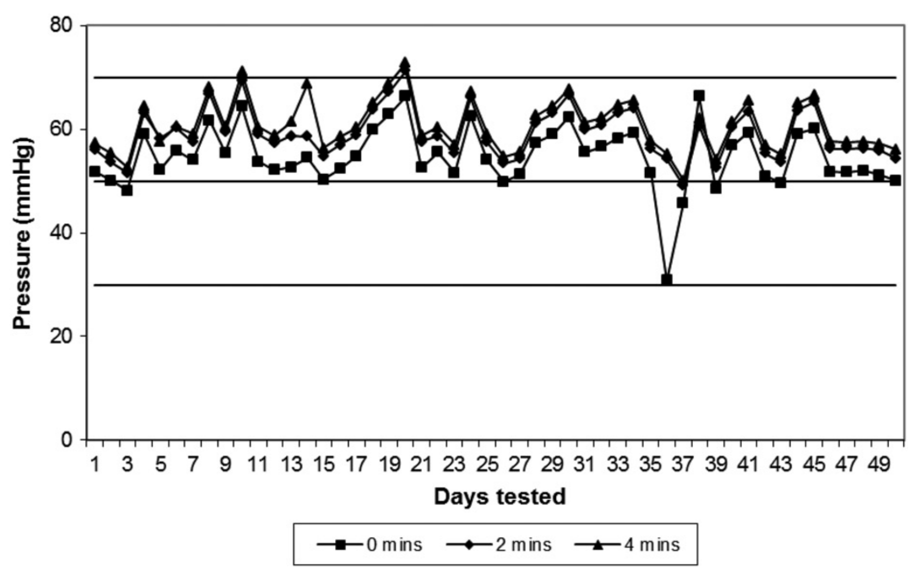


Figure 4. Results of the longer term testing (average pressure data) at 50 mmHg with range between 30–70 mmHg.



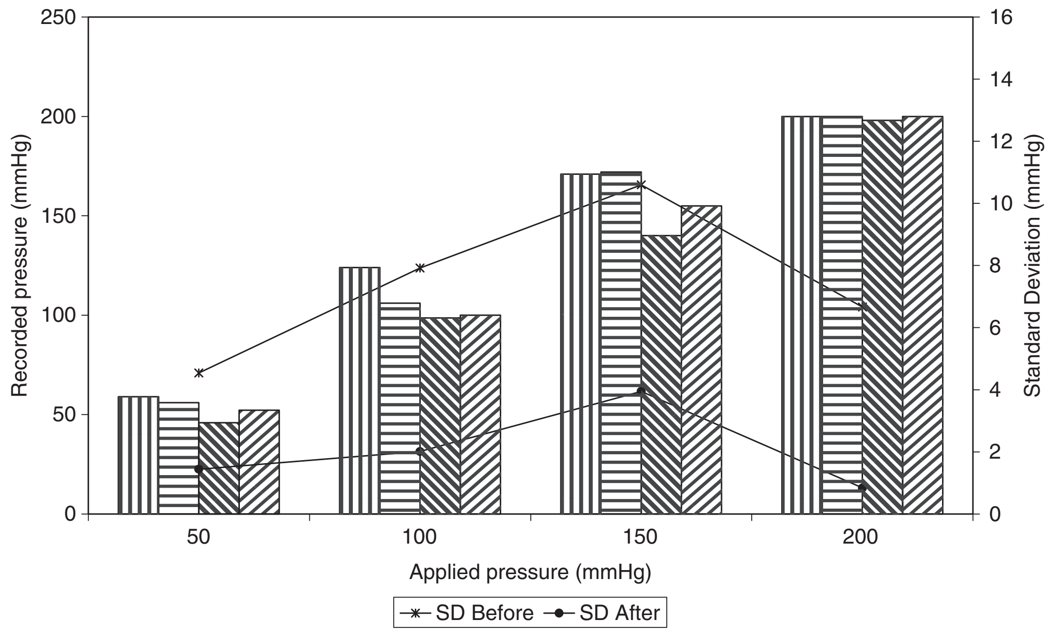


Figure 5. Results of the effect of calibration with the black mat. Bars from left to right: Maximum pressure before (vertical), Maximum pressure after (horizontal), Average pressure before (left diagonal) and Average pressure after (right diagonal).

For the standard deviation results the data was separated into different categories and then analysed. The categories were:

- *Time*: All standard deviation data at 0 min (manual, autocalibrator and autocalibrator with new software). This was then repeated for 2 min and 4 min (i.e. keeping the duration of applied pressure constant but changing the calibration method), and
- *Calibration method*: All standard deviation data using manual calibration (0, 2 and 4 min). This was then repeated for autocalibration and autocalibration with new software (i.e. keeping the calibration method constant but changing the duration of applied pressure).

The analysis consisted of calculating the mean and standard deviation of each set of data to determine the best calibration method and best duration of applied pressure. Ideally, if the mat was perfect, the standard deviation should be 0, therefore the closer the result to 0 the better the data.

3.2. Longer term testing

The manufacturer states that the actual reading of each sensor at every validation pressure level should be within ±10% of the final calibration pressure, with respect to the pressure level. In this case the final calibration pressure is 200 mmHg and 10% of this is 20 mmHg. If reading is at a pressure level of 100 mmHg, the range the pressures should fall between 100 mmHg ± 20 mmHg, i.e. 80–120 mmHg. For a pressure level of 50 mmHg the range is 30–70 mmHg.

Figures 3 and 4 show a banding of ±10% of the final calibration pressure. The three lines represent the time period of recording – 0, 2 and 4 minutes.

3.3. Effect of calibration

Figure 5 shows the before and after comparisons of Maximum Pressure, Average Pressure and Standard Deviation for the black mat. The bars represent the pressures, while the lines represent the standard deviations.

4. Discussion

Once a mat has been calibrated, ideally, all the sensors should show an equal pressure when exposed to the same pressure, with a low standard deviation.

The results expected from a true pressure mapping system are:

- *Maximum Pressure*: Increases over time due to individual sensor creep;
- *Average Pressure*: Increases over time due to general sensor creep; and
- *Standard Deviation*: Close to 0 as possible. Would remain relatively constant with time.

From the pilot study, it can be seen from Table 1 that, for calibration purposes only, across all the data, the autocalibrator needs to be used, with or without the new software. There are several other conclusions that can be drawn from this table:

- There is no significant difference between mats,
- Apart from 2 min and 4 min at 50 mmHg, there is a statistically significant difference between calibration methods,
- The best calibration method when testing at 100 mmHg was the autocalibrator,
- The best calibration method when testing at 50 mmHg was either the autocalibrator and new software or manual, and
- The best time to take reading was at 0 min with both mats, with the autocalibrator and new software.

The only problem with the ANOVA test is that it cannot tell you which specific groups were significantly different from each other (just that the groups were different). To determine which specific groups differed from each other, extra detailed analysis would need to be done.

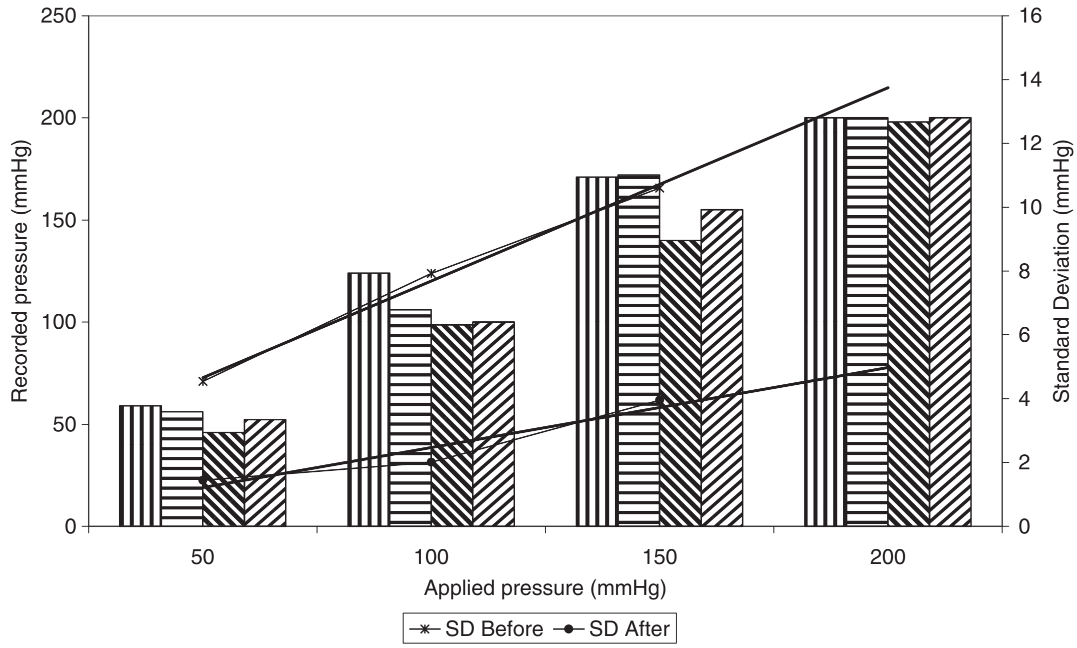


Figure 6. Results of the effect of calibration with the black mat with standard deviation extrapolated.

Also, if analysing the longer term testing where the Average Pressure results should be within ±10% of the final calibration pressure (200 mmHg), the readings should be between 80–120 mmHg at 100 mmHg pressure and between 30–70 mmHg at 50 mmHg. All results for both mats fall between these ranges. This specification is too broad and it should be ±10% of the measurement pressure rather than the final calibration pressure, i.e. if reading at 100 mmHg the range should be 90–110 mmHg rather than 80–120 mmHg and between 45–55 mmHg for 50 mmHg reading. Looking at the results with this in mind, the best time to take a reading is at 0 min with the autocalibrator and new software which supports the ANOVA analysis above.

When looking at the standard deviation data (Table 2), for both the 100 mmHg and 50 mmHg data, the best time to read is at 0 min and the best calibration method is autocalibrator with new software. The mean of the standard deviations is low, with the maximum at 7.98 mmHg and maximum standard deviation 3.27 mmHg.

For the longer term testing (Figures 3 and 4), most of the data falls within the bands specified, with only a few exceeding the range. Five per cent of the points fell outside of the band for 100 mmHg and 2% for 50 mmHg. Again, if we change the banding to ±10% of the measurement pressure, then this changes the analysis dramatically, with 34% points falling outside of the 100 mmHg band and 73% points falling outside the 50 mmHg band. This shows that, without regular calibration, the readings increase over time, giving inaccurate results.

From the graph of the Effect of Calibration (Figure 5) it can be seen that there is a fairly large increase in standard deviation, roughly doubling over a period of 1 month. The 200 mmHg readings of standard deviation are false, as the highest pressure that can be recorded on the mat is 200 mmHg, therefore if most of the sensors record this high pressure, the standard deviation will be low. If the standard deviation line is extrapolated (see Figure 6), it can be seen that it would roughly increase to 14 mmHg and 5 mmHg for the before and after results, respectively. Therefore, this shows that regular calibration is essential.

Gathering data from all the above tests show that the best time to take a reading is at 0 min with the autocalibrator and new software. After looking at the results of the longer term testing and Effect of Calibration it was decided to calibrate the mats in Swansea at least every 2 months using the autocalibrator and new software. This frequency was decided as the average usage per month is ∼15 and this should account for up to a maximum of 30 clinical uses of the mat before the deviations start (conclusion from the longer term testing). Also, regular calibration and checks of the mat are crucial in the performance of the system, therefore 2 months was decided.

The calibration and testing of the mat in the calibration jig are subject to a number of variations. For example:

- The air bladder can relax with time (slightly leak air) when measuring at a specific pressure. This was verified by checking the pressure during the time of applied pressure. The variation was very slight (±2 mmHg) as measured by the sphygmomanometer.
- The sphygmomanometer was calibrated at the start of the experiments to make sure it was reading the correct pressure. It was also checked at the end of the study and there was no change at a specific pressure.
- There could also be issues with the friction between the mat and air bladder which could alter pressure readings.
- There could have been variations in the force applied by the bladder due to variable contact with the mat.
- The rate of change of input pressure into the air bladder could affect the readings, especially when manually calibrating, as sometimes the air input would be fast and sometimes slow. This was controlled when using the autocalibrator as it pumps air in at a constant rate.

Also the time duration held at each specific applied pressure when manually calibrating can effect the creep, again this was controlled by using the autocalibrator.

After liaising with the manufacturers about the tests being performed, they stated that the calibration jig would not be an appropriate test rig as the mat is designed for use with patient movement e.g. blood flow. In a calibration jig, all the sensors are activated and the electronics are working to their maximum capacity, which does not provide a true clinical reading. The hysteresis and creep accommodations built into the software assume patient movement; therefore the mat should be tested in a dynamic situation. Based on previous experimental work in this area [10] it was decided to initially use the calibration jig to test for linearity (readings correlated to the known applied pressure) and stability (monitoring output over time to detect any creep or changes in readings when load is kept constant) to review the performance of the mats.

The tests performed above are very similar to the ones carried out by Ferguson-Pell and Cardi [10]. In this study the pressure mat was placed in a calibration jig with the load increased in increments of 20 mmHg up to 160 mmHg and output parameters recorded. This was repeated 5-times. Also, pressures were applied at 50 mmHg and 100 mmHg with readings taken immediately and at 1-min intervals for 10 min. The results from this study showed a low correlation coefficient and high standard deviation in the lower pressure range for the FSA system. The system also showed some inconsistency during the stability test over 10 min due to increased creep and hysteresis, mostly during the first 2 min following loading. It was recommended from this study that there should be a 10 min delay, to wait for the pressure values to stabilize, but, clinically, this is impractical. The mat construction and software have been changed and developed significantly since the publishing of Ferguson-Pell and Cardi [10] work, so the data cannot be compared to the mat currently used in the Swansea testing.

Comments from the manufacturers after showing them the results of the above tests stated that they have been aware of the need to address the unreliability of the mats resulting in the systems needing frequent calibration. They now have a weight calibration refinement technique that replaces the full calibration with a quick refinement for older mats. Also a new mat has been developed, which does not seem to show the same need for frequent calibration. They have run a 100 000 cycle load testing and the mats seem to improve with use up to that point. This should improve the reliability and accuracy of the mats, but, in the author's opinion, frequent (2-monthly calibration) is still required to maintain the mat and ensure optimal performance of the system.

In conclusion, pressure mapping is being used more and more in clinical practice, therefore accurate systems are required to produce reliable results. Although they are a useful tool, they should not be a substitute for clinical judgement in the assessment and treatment of pressure sores, as pressure is only one aspect of developing pressure sores and a more holistic view needs to be investigated. The readings from the pressure mapping system should not be treated as absolute values, i.e. should only be used as a comparative measure. An example of this is if a set weight is placed on the mat, removed and placed again, the readings will be different. The mats do need to be handled carefully and continuously checked for stability and consistency. Calibration of the mat is an essential part of the system to make sure it works to its full ability and it should be calibrated at regular intervals, as suggested by this study, every 2 months is ideal.

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Study of the experience of carers in the management of dementia patients with incontinence: is there a need for sensor technology?

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SYNOPSIS

The condition of urinary incontinence (UI) often determines whether a person can be managed at home or is admitted to a care home, where UI tends to be managed through routine checks and toileting. UI detection is critical since if undetected or resolved following checks; this can result in indiscriminate use of pads and unnecessary service referrals, ultimately inhibiting the promotion of continence and increasing the likelihood of disease. This study examined current incontinence management methods for dementia patients in care homes and obtained carer views regarding the use of a sensor technology device to support current protocols. The outcome will inform the design of future devices and determine the perceived usefulness and likelihood of such devices being used in the monitoring of humidity and temperature changes as an indicator of incontinence.

1. INTRODUCTION

Dementia, a condition that affects the aging population, can cause a profound effect on daily lives (loss of personality and planning skills) impacting on the person's ability to remain continent (Getliffe and Dolman, 2007). UI is the complaint of involuntary leakage of urine (Abrams et al., cited in Getliffe and Dolman, 2007). Commonly, patients do not seek treatment for incontinence as it is not viewed as a legitimate medical condition; rather it is considered a normal part of ageing (Shaw and Brittain, 2007). However in dementia patients, incontinence has often been cited as the final straw that influences whether a person can be managed at home or admitted to institutional care (Thom, 1997).

A health outcome report (National Centre for Health Outcomes Indicators, 2000) suggested that 30% of people living in Residential care homes were incontinent, rising to 60% in Nursing homes. The problems identified in care homes include, variations of treatment, proportion and relative availability of staff and quality of education (Department of Health, 2000). Although routine checks and toileting regimes exist, urinary accidents are sometimes undetected or only resolved at the next check. This suggests that continence may not be encouraged causing indiscriminate use of pads and unnecessary referrals to expensive services (Royal College of Physicians, cited in Getliffe and Dolman, 2007). Better understanding and application of technology and products to improve lifestyle might prevent the use of pads and encourage the promotion of continence; leading to improved quality of life.

This project studies the use of sensor technology embedded in the seat or attached to clothing close to the skin in order to measure temperature and humidity at these interfaces. Increases in skin temperature and moisture from sweating or UI, can cause skin maceration, weakening the damaged skin making it more susceptible to poor healing and infection (Ferguson-Pell, et al., 2009). If a person cannot detect urinary leakage which could lead to changes related to early stages of skin damage maybe sensor technology could be of benefit (McCarthy, et al., 2009).

1.1. AIM

The aim of this study is to examine the methods of managing incontinence and to support current protocols, through obtaining carer views regarding the potential use of sensor technology.

2. METHODOLOGY

The project was initiated with funding and direction via the Strategic Insight Programme (SIP) involving an external consultant (Evolution IS) to provide guidance on identifying and obtaining customer data requirements. The core method involved a voice of the consumer survey (initial phone interviews, to qualitatively assess the initial interest for the suggested product) and from this the design of a semi-quantitative questionnaire designed to increase our understanding of the carer's needs and management procedures. Carers made up the initial broad sampling framework.

3. FINDINGS

1) The phone interviews revealed that there was interest for the use of sensor technology in care homes. 23 (45%) of 52 English care homes, and 16(30%) of 51 Welsh care homes expressed an interest in the study (figure 1). Expressing interest in this study means that the care homes were interested in participating in a questionnaire study referred to in figure 1 as a 'Yes'. The 'No' represents the care homes that were not interested in the idea and stated a preference for traditional visual monitoring methods over technology.
2) A semi-quantitative questionnaire was then developed and piloted for content validity by requesting the opinions of two care home managers and an Incontinence nurse specialist. They reported that the questionnaire was suitable for deployment.
3) All the care homes are privately owned (not NHS) therefore ethical approval was sought from the faculty of health, sport and science Ethics Committee of the University of Glamorgan. Data from this will be presented at the meeting.

3.1. FIGURES

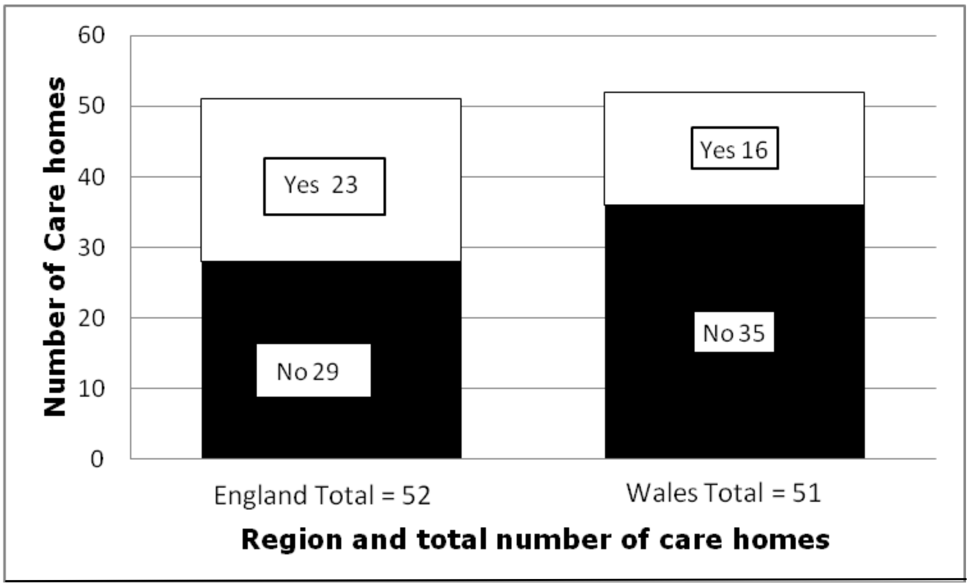

Figure 1: Phone interview results for care homes in England and Wales

4. CONCLUSION

Although rudimentary, these data support a limited interest for the use of a technological approach to the problem of urinary incontinence in this setting. It is generally considered within those with an interest that such a detection device could aid general care home management and audit of patients / residents with this condition. This conclusion has the caveat that the outcome of the questionnaire will determine the constraints that will affect the design of the final device and its usefulness to monitor changes due the occurrence of incontinence.

5. REFERENCES

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Study of the experience of carers in the management of dementia patients with incontinence: is there a need for sensor technology?

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Abstract

This study examined current incontinence management methods for dementia patients in care homes and obtained carer views regarding the use of a sensor technology device to support current protocols. The outcome will affect the design of any device and determine its usefulness to monitor humidity changes at the skin surface.

Introduction

Dementia, a condition that affects the aging population, can cause a profound effect on daily lives (loss of personality and planning skills), impacting on the person's ability to remain continent [1]. Urinary Incontinence (UI) is the complaint of involuntary leakage of urine [2]. Commonly, patients do not seek treatment for incontinence as it is not viewed as a legitimate medical condition; rather it is considered a normal part of ageing [3]. However in patients with dementia, incontinence has often been cited as the final straw that influences whether a person can be managed at home or admitted to institutional care [4].

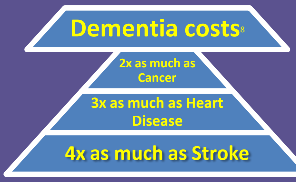
A health outcome report has suggested that 30% of people living in Residential care homes were incontinent, rising to 60% in Nursing homes [5]. The problems identified in care homes include, variations of treatment, proportion and relative availability of staff and quality of education [6]. Although routine checks and toileting regimes exist, urinary accidents are sometimes undetected or only resolved at the next check. In this context, continence may not be encouraged causing indiscriminate use of pads and unnecessary referrals to expensive services [7]. Better understanding and application of technology and products to improve lifestyle might prevent the use of pads and encourage the promotion of continence; leading to improved quality of life. Table 1 shows the impact of Dementia and Incontinence on the UK economy annually.

Table 1: The number of people affected by the conditions and its impact on the UK economy

Condition	Number of people in the UK	Cost to the UK economy annually
Incontinence (Urinary/Faecal)	5million	£420million[1]
Dementia	821, 884	£30,000 per patient[8]
Estimated : 80 -90% of Dementia sufferers have Incontinence (Urinary/Faecal)[9]		

Long term Institutional Social Care and Informal Care of Dementia Patients cost the UK economy

£23 billion annually [8]



Currently there is a lack of research into management of incontinence in dementia patients and that needs to be resolved to improve the lives of long term sufferers.

Future developments of incontinence treatments appear to show improvement in symptoms, but whether they are suitable for dementia patients, needs to be researched [9].

Methods: Study Description

The aim of this study was to examine the current methods of managing UI and to support current protocols, through carer views regarding the potential use of sensor technology in this area. The outcome will inform the design of future devices and determine the perceived usefulness and likelihood of such devices being used in the monitoring of humidity and temperature changes as an indicator of incontinence.

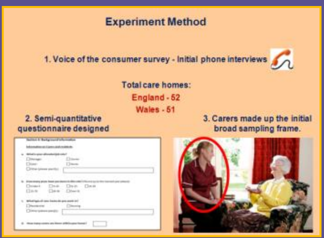


Figure 1. Experiment Method for questionnaire deployment

Figure 1 shows the core methodologies involved which were:

1. The voice of the consumer survey (initial phone interviews, to qualitatively assess the initial interest for the suggested product).

2. A semi-qualitative questionnaire was developed for interested care homes.

3. Carers made up the initial broad sampling framework.

A total of 52 and 51 care homes (England and Wales respectively) were contacted via telephone.

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Results of study

The phone interviews revealed that there was interest for the use of sensor technology in care homes. The following proportions expressed interest in the study (also in figure 2):

- 23 (45%) of 52 English care homes
- 16 (30%) of 51 Welsh care homes

Expressing interest in this study means that the carers from the care homes were interested in participating in a questionnaire study referred to in Figure 2 as a 'Yes'.

The 'No' represents the care homes that were not interested in the idea and stated a preference for traditional visual monitoring methods over technology.

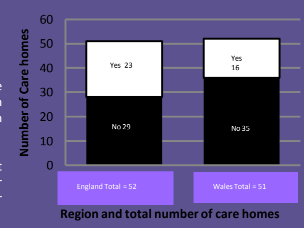
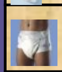
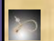
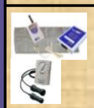


Figure 2. Care homes and their region

The voice of survey revealed that incontinence is managed through the following ways:

Aids	Management strategies
	Toileting strategies works successfully with people who have less severe dementia and also who are more mobile.
	As dementia progresses patients may be more reliable on containment aids such as pads . People who are reliant on pads are changed about 3-4 times in the day and the same in the night.
	Urinary aids for male and females help the user to be more self reliant and confident about continence issues.
	Catheterisation is also used as a method of incontinence management for patients who are terminally ill and distressed by their incontinence
	Technology include electrical nerve stimulation and enuresis monitors however carers from phone survey seem to prefer traditional approach to management. Training and cost implications exists as well as more research extending past experimentation and unproven techniques need to be carried out.

A semi-quantitative questionnaire has since been developed and piloted for content validity by requesting the opinions of two care home managers and an Incontinence nurse specialist. A snap shot sample is shown on Figure 1. The questionnaire has been reported to be suitable for deployment. , ethical approval is currently being sought. All the care homes are privately owned (not NHS).

Conclusion and Further work

- Although rudimentary, these data suggest that the current methods of assessing for incontinence in patients with dementia in care homes is neither uniform nor adequate.
- The evidence suggests that the system cannot support a route back to continence.
- There appears to be support for an incontinence detection device that could aid with general care home management.
- This conclusion has the caveat that technological feasibility might be less than the concepts held by the care workers in this area.
- Therefore, the outcome of the questionnaire will be used to resolve these issue by determining the constraints that will affect the design of the final device and inform regarding the perceived potential to monitor changes due the occurrence of incontinence.

Faculty of Health, Sport and Science

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Recognising sensor technology characteristics to measure humidity changes for future urinary incontinence detection

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Abstract

This study explored the interaction between humid environments and the humidity sensors to better understand and develop the application of sensor technology for this purpose. These sensors were placed in different experimental environments with or without a micro weave cover in order to test the reliability of the sensor characteristics and to have confidence in the measurement limits. Sensors were also calibrated in a humidity chamber that is traceable to National Standards.

Introduction

Urinary incontinence (UI) refers to a complaint where there is involuntary leakage of urine [1]. UI can affect people of all ages although it is prevalent in dementia sufferers . Dementia, a condition that affects the aging population, causes to the loss of personality and planning skills due to the progressive neurological damage, ultimately impacting on the person's ability to remain continent [2].

Skin moisture (from incontinence) is considered an exacerbatory factor to the effects of mechanical damage due to shear and friction forces while sitting or lying for prolonged periods [3-5]. This could increase the risk of pressure ulcers formation.

In dementia sufferers who are unable to respond to their own neurological feedback, perhaps sensor technology could be of benefit [6]. Although many humidity and temperature detection methods have been created, problems exist such as invasiveness, single use or being only capable of research use.

Further limitations of sensor technology result from poor reaction times for detection or propensity for false triggering of alarms, resulting in poor exploitation of technology.

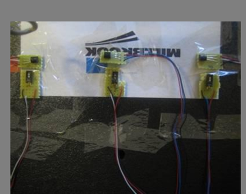
Research on a previous project appeared to show that humidity sensors could recognise changes in humidity at the skin-seat surface even when the sensor was placed inside a sealed fabric bag (micro weave cover). This serendipitous finding has formed the basis for this study.

Study description

Four varieties of moisture experiments were performed in this study to determine whether the humidity sensors were capable of detecting water vapour with and without the micro weave cover.

The experimental methods for these four experiments are described in Table 1.

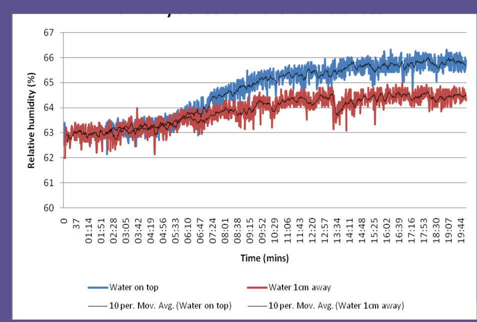
Table 1: Experimental method description

Experiment	Method	System description
1. Distance	Water was dropped on top and 1cm away from humidity sensors which were covered with a micro weave cover to protect them from the direct moisture.	
2. Interval	Water dropped consecutively (one minute intervals) on top of three sensors with the protecting micro weave cover over them.	
3. Saturated and dried	Two conditions were assessed. The first is a damp state that the humidity sensor is assumed to be in due to usage and exposure to ambient air. The second state involved the sensor being dried by a fan blower to remove any moisture trapped inside its casing. The sensors were activated without a micro weave cover.	
4. Humidity chamber	Humidity sensors were placed in a humidity chamber, set at 20˚C and 32˚C at ascending and descending humidity values of 10%, 25%, 50%, 75% and 90%. The sensors were activated without a micro weave cover.	

Experimental results

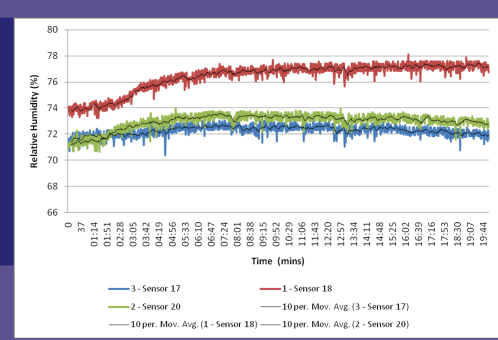
The sensors were tested with and without a micro weave cover in four conditions.

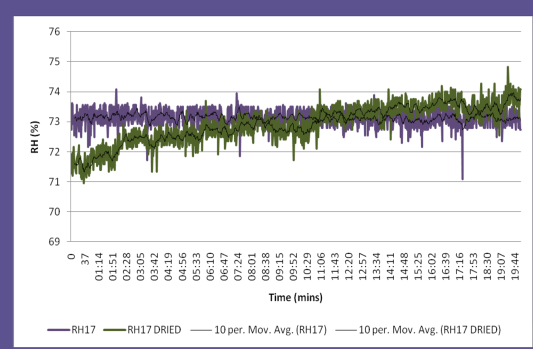
The results are displayed in the following four diagrams.



Distances experiment: Sensors can detect change in moisture through a micro weave cushion cover. The peak increase of the blue line indicates: water dropped on top of sensor. The red line indicates: water dropped on the same sensor 1cm away.

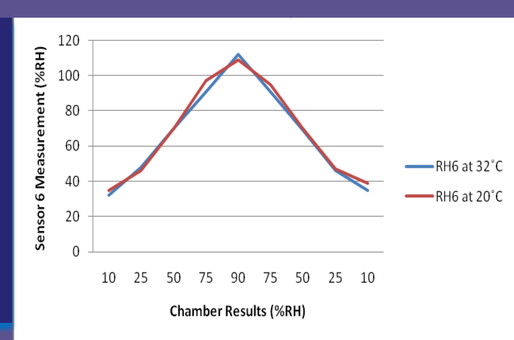
Interval experiment: Sensors detected change between 15 and 30 seconds after water was dropped on each sensor in turn. [Line indicators: 1st drop: green, 2nd drop : red, 3rd drop : blue]





Saturated and dried experiment: The purple line (saturated sensor) showed no obvious change in measurement. The green line (dried sensor) showed a significant change.

Humidity experiment: Sensors recorded higher humidity values than equivalent humidity chamber setting: At 20˚ C sensors measured 22% higher. At 32˚ C the sensors measured 20.4% higher.



Conclusion and further work

The findings from all four experiments are brought together below and presented to highlight the key characteristics about the system:

1. **Distances experiment:** Sensors detect water vapour at two distances through a micro weave cover. Best placement of sensors for detecting body humidity.
2. **Interval experiment:** Sensors can detect water vapour within a time frame through a micro weave cover. Regular calibration and choice of cover could encourage consistent detection time.
3. **Saturated and dried experiment:** Sensors need to be housed appropriately before embedding into a seat or bed, to inhibit the potential creeping of moisture which could reduce sensitivity and lifespan of sensors.
4. **Humidity experiment:** Recalibration of sensors and further testing would be useful to determine its' lifespan. Current discrepancies would involve a factor value to match the true value.

The next step would be to develop a prototype device and to investigate the application of sensor technology with respect to humidity from urinary incontinence in dementia patients. The design of this prototype would be partially based on the results from the questionnaire from care home participants.

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Using technology to enhance self care

University of South Wales
Prifysgol De Cymru

CTDRU
clinical technology and diagnostics research unit

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Although it is accepted that with aging come problems, we follow Theodore Roosevelt in believing "***Old age is like everything else. To make a success of it, you've got to start young."*** An informed approach to self care may be the key in protecting the body from accelerating the rate of deterioration which is an accepted consequence of the ageing process. Technology can now be used to help increase self-awareness by recognising risks early, ameliorate or even prevent damage and initiate appropriate rehabilitation.

The Clinical Technology and Diagnostics Research Unit (@CTDRU) has diverse interests, bringing a multidisciplinary approach involving CAM and technology to meet the three research areas (seen below). We believe that is not just patients that need greater personal awareness, embracing technology could generate useful tools for facilitating and maintaining independent living at all stages of our lives.

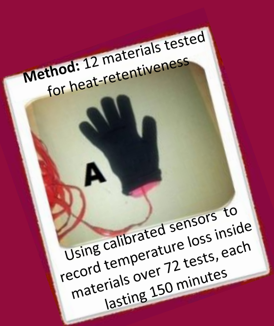
Research Area 1

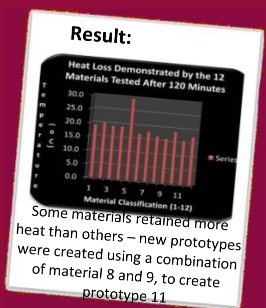
Non invasive treatment and system quantification for Raynaud's disease: Comparing heat retention in materials

Introduction

Raynaud's disease is a condition which is characterised by excessively cold and numb fingers due to insufficient blood perfusion[1]. Raynaud's gloves on the current market are reported to be flawed in design[2], and it was decided that the best way to approach creating improved gloves was to test materials, then combine the materials with the most effective properties to maximise heat retention, whilst preserving dexterity with the aim of promoting independence and quality of life.

Methodology and Results





Conclusion

Creation of gloves increases the ability to perform ADLs – Promotes independence and increases quality of life

Research Area 2

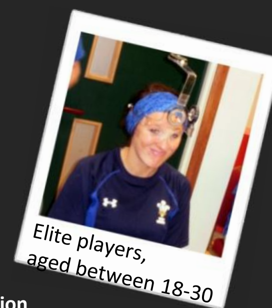
Cervical Range of Motion in Elite Rugby Union Players

Introduction

Neck function can be easily compromised and is generally expected to decrease with age. This study was therefore designed to determine if playing a contact sport such as rugby union decreases cervical (neck) active range of motion in the elite game.

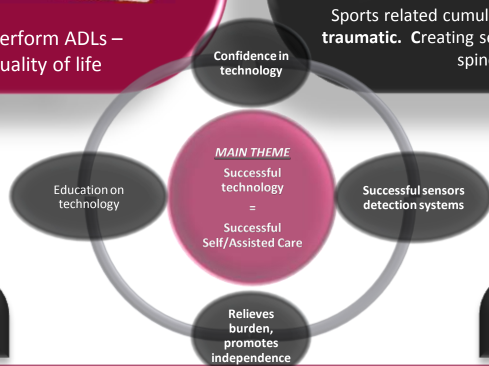
Methodology and Results

By studying elite sportspeople we have discovered this might be exacerbated by lack of awareness. Most noticeable to date was the finding that participants (as below) can have the same neck function as geriatrics and those with whiplash associated disorders!



Conclusion

Sports related cumulative damage to the neck can be ignored if not acutely **traumatic. C**reating self awareness and rehabilitative might mitigate cervical spine degeneration in these elite athletes.



Method 1: Care home questionnaire study

Methodology

This study investigated the views of carers on using sensor detection technology in line with their current management protocol.

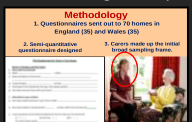


Figure 1: Study methodology

Results and Conclusion

21 questionnaires were returned : England 9 and Wales 12.
71% of the carers (15 homes) agreed, sensor technology may benefit.
However 5 said it would not. One home did not answer.
The table below shows some comments by the carers.

	Could sensor technology aid carers in managing incontinent dementia residents?	
No. of carers	Yes	No
	15	5
Reasons	**Reduce incidence of incontinence** **Identify patterns for passing urine** **Enhance dignity of residents** **Tend to residents quicker** **More discrete for resident**	Residents regularly checked, prefers this traditional approach (Individual care is already provided - suitable for hospital use

The carer's feedback will assist in the design of a system that could benefit their management of incontinence. Efficient management will increase the quality of life of incontinent dementia residents, allowing them to age with dignity.

Research Area 3

The application of sensor detection systems in care homes

Introduction

Dementia sufferers often develop incontinence[6]. However, dementia sufferers view attempts to maintain continence as intrusive, resulting in behavioural problems [7]

Carers commend traditional approaches to maintaining continence, however many also consider technology could avoid delays in checking and limit intrusion on those who are already unaware of their deficits[8].

Aim

This study aims to investigate the feasibility of using technology to overcome communication barriers between carers and sufferers and will be carried out in two methods, 'a care home questionnaire study' and a 'sensor detection system study'.

Method 2: Sensor detection system study

Methodology

Figure 2 shows the average sensor output of 11 healthy participants aged 19 to 34 years. The participants were required to sit on sensors (embedded in a foam cushion with three surface coverings) located under their thigh and coccyx region for 40 minutes.

Results

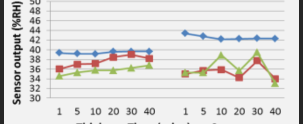


Figure 2: Sensors measuring participants thighs and coccyx

Sensors display sensitivity. Measures of thighs and coccyx of participants on 3 surfaces:

Blue line: Sensors exposed with no cover
Red line: Sensors with a cover
Green line: Sensors placed in encapsulated bags.

Conclusion

Establishing the accuracy and reliability of sensors will help to determine an appropriate system that could assist with detecting incontinence. The design of a system should complement the management of incontinent dementia residents.

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