Energy Efficiency (2021) 14: 92
https://doi.org/10.1007/s12053-021-10003-y

ORIGINAL ARTICLE

Thinking inside the box: new ways of considering energy consumption in a multi-user agency-constrained environment

Ksenia Chmutina · Andrew Dainty · Robert Schmidt III · Elli Nikolaidou · Eirini Mantesi · Yang Yu · Malcolm Cook

Received: 16 December 2020 / Accepted: 20 October 2021 / Published online: 7 December 2021

Abstract Reductions in end-use energy imply some level of technological and behavioural change — yet there are marked differences in the balance between them. Moreover, the ways in which these influences can combine and mutually shape each other are complex, especially where multiple users interact within the same environment. A socio-technical perspective has gradually become more popular in building energy research in recent years, as it widens the focus beyond technology to include practices, infrastructure, markets, policies, social norms, and cultural meanings; however, there is very little knowledge on *how* this interplay works — particularly in a non-domestic environment. In this paper, we attempt to enhance the understanding of 'social ordering of choices, problems and practice' (Guy & Shove, 2000, p. 139) within a retail environment — and how these are competing when it comes to decisions about energy consumption. Using a longitudinal multi-methodological case study approach, this paper aims to explicate the socio-technical context within which energy consumption is considered by various actors in a large supermarket given that these actors have other behaviours (e.g. convenience, profit) as a priority and that the retail environment is agency constrained (i.e. shoppers, employees can hardly do anything individually to affect energy consumption). Using mixed-reality platform, we visualised socio-technical interactions, thus also visualising the decisions on where energy efficiency interventions could be made, what needs to be considered, and how this differs from different perspectives. Priorities that often remain 'unspoken' become visible — and thus provide a powerful foundation for the discussion about the consequences of an intervention there and then thus reduce the complexity of discussions and keeping crucial information available during the entire discussion process.

Keywords Socio-technical interplay · Retail environment · Energy efficiency · Mixed reality design platform

Introduction

Reductions in end-use energy demand can be achieved in several ways: by improving the efficiency of existing energy-using devices and passive systems; by replacing existing devices or passive systems with radically new ones; by shifting towards lower-energy behavioural practices; through reducing demand for particular energy services; or by developing entirely

K. Chmutina (✉) · A. Dainty · R. Schmidt III · E. Mantesi · Y. Yu · M. Cook
School of Architecture, Building and Civil Engineering, Loughborough University, Loughborough LE11 3TU, UK
e-mail: k.chmutina@lboro.ac.uk

E. Nikolaidou
Department of Architecture & Civil Engineering, University of Bath, Bath BA2 7AY, UK

new socio-technical systems that use less energy. Whilst all these options imply some level of technological and behavioural changes, there are marked differences in the balance between them (Geels et al., 2015). Moreover, the ways in which these influences can combine and mutually shape each other are complex, especially where multiple users interact within the same environment (Christina et al., 2014, 2015).

In recent years, energy consumption reduction has been largely looked at through the engineering/maintenance lens (e.g. technology performance) (Sweeney et al., 2013), and more recently the behaviour aspect — particularly in domestic sector (Delzendeh et al., 2017; Pothithou et al., 2016; Van den Broek & Walker, 2019) — has also been recognised. A socio-technical perspective has gradually become more popular as it widens the focus beyond technology to include practices, infrastructure, markets, policies, social norms, and cultural meanings (Geels et al., 2015). Whilst it is agreed that the interplay between technology and energy behaviour exists, there is very little knowledge on *how* this interplay works — particularly in a non-domestic environment. To address this gap, we attempt to enhance the understanding of 'social ordering of choices, problems and practice' (Guy & Shove, 2000, p. 139) within a retail environment — and how these are competing when it comes to decision about energy consumption.

Using a longitudinal multi-methodological case study approach, this paper aims to explicate the socio-technical context within which energy consumption is considered by various actors in a large supermarket given that these actors have other behaviours (e.g. convenience, profit) as a priority and that the retail environment is agency constrained (i.e. shoppers, employees can hardly do anything individually to affect energy consumption). 'Literature review' highlights the agency-constrained nature of the retail environment and the differences that user behaviours can make to energy consumption. 'Methodology' introduces the multi-methodological case study approach that includes hard performance data and the qualitative data. 'Results and discussion' and 'Conclusions' explicate how the socio-technical context within which energy consumption is considered by various actors in an agency-constrained environment — and what are the implications of making the challenges of such context more visible.

Literature review

Retail and energy

Considering the rising energy costs and relevant environmental concerns, energy demand has been increasingly used as an indicator of the performance of buildings throughout their lifespan (Elbeltagi et al., 2017). Taking into account such a performance indicator to inform design decisions is of critical importance in the context of the commercial sector and especially in retail, where the highest energy consumption rates are observed (Pérez-Lombard et al., 2008). Retail stores account for 9% of total CO_2 emission in the European building stock (Building Performance Institute Europe, 2011, as cited by Ferreira et al., 2020), while the average total energy consumption of a retail store is calculated to be around 1000 kWh/m^2 per year, a figure which is significantly higher than the corresponding energy consumption of other commercial buildings, such as offices (100–200 kWh/m^2 per year) or hotels (100–300 kWh/m^2 per year) (Galvez-Martos et al., 2013). Especially when refrigeration systems are used, the energy intensity of retail buildings is significantly higher (Schönberger et al., 2013). Food retail stores sector amounts about 3% of EU members' electricity consumption (Gimeno-Frontera et al., 2018).

According to the Building Energy Efficiency Survey (BEIS, 2016), retail is responsible for the 17% of UK's total non-domestic energy consumption. The average energy intensity of large food stores is estimated to be around 565 kWh/m^{2}y (ranging from 400 to 740 kWh/m^{2}y), 70% of which is electricity consumption, being mostly associated with heating and ventilation, lighting, catering, and cooled storage.

Predicting and optimising energy use in supermarkets is extremely difficult due to the interdependence of their end-use sub-systems. Refrigeration, heating, cooling, ventilation, and lighting are all factors which act simultaneously in food retail buildings, affecting both their energy consumption and their thermal environment. Lighting is cited as one of the most important technologies considered for marketing purposes. Effective lighting can increase shoppers' satisfaction and encourage them to spend more time in stores (Gerdeman, 2007; Tassou et al., 2011). Indoor air quality (IAQ) is another important component in energy management for retail stores due to not only the building regulations but also customers' satisfaction (Zaatari et al., 2016).

In addition to refrigeration and space conditioning systems, the energy consumption of food retail buildings is highly dependent on further requirements, related to product preparation, preservation, and display, store operation schedule, and the transient occupancy patterns (Iyer et al., 2015; Mylona et al., 2017). According to Spyrou et al. (2014), the end-use-related factors of supermarkets can be grouped into three main categories: those that describe the physical characteristics of building (i.e. store size, thermophysical properties of envelope), those that are related with the operational characteristics of individual stores (i.e. opening hours, stock composition), and finally the regional characteristics of a building (i.e. location of stores).

There are several previous studies which investigated best practice to promote energy efficiency and carbon savings in retail buildings (Ferreira et al., 2020; Fieldson & Rai, 2009; Galvez-Martos et al., 2013; Gimeno-Frontera et al., 2018; Iyer et al., 2015; Jenkins, 2008; Kolokotroni et al., 2015; Kolokotroni et al., 2019; Mylona et al., 2018; Schönberger et al., 2013; Spyrou et al., 2014; Tassou et al., 2011; Timma et al., 2016).

Tassou et al. (2011) analysed the energy consumption data of 2570 retail food stores in the UK and found that energy consumption in supermarkets varies widely and depends on many factors, such as the type and size of store, business and merchandising practices, product mix, shopping activities, refrigeration and environmental control systems used, and equipment used for food preparation, preservation, and display. Refrigeration systems account for 30–60% of electricity used, lighting is responsible for around 15 to 25%, and the remainder of energy consumption is attributed to HVAC systems and other utilities. Electricity typically accounts for more than 70% of energy consumed in UK supermarkets. Finally, the study concluded that if energy intensity of stores above-average use is reduced to average, by energy conservation measures, annual energy savings of up 10% can be achieved.

Gimeno-Frontera et al. (2018) presented a methodology based on life cycle assessment (LCA) standards as a way to estimate environmental impacts of non-domestic buildings, in particular food retail stores. Their findings suggest that combining the use of environmentally friendly refrigerants and energy efficiency measures in lighting and HVAC systems could potentially lead to environmental impact savings of up to 80%.

Current studies in the UK show that operational low carbon supermarkets are capable of saving up to 66% of GHG emissions compared to a conventional store (Kolokotroni et al., 2015). In fact, published literature indicates that UK supermarkets have significantly improved their operational efficiency over the last decades (Sullivan & Gouldson, 2013). According to the British Retail Consortium (2014, as cited in Kolokotroni et al., 2015), any progress made since mid-2000s is mainly due to improvements in energy monitoring and control systems, improvements in energy-efficient technologies used in stores, and staff training and behaviour change in energy use, among others.

The replacement and more efficient control of HVAC, lighting, and refrigeration systems, as well as of equipment (e.g. rotisseries and ovens), represent great energy-saving opportunities that should attract the interest of retailers who wish to minimise the environmental impact of their stores (Acha et al., 2013). The corresponding investment costs may, however, prevent the implementation of these energy-saving measures, with small retailers being more vulnerable to this possibility, compared with their larger counterparts (Dixon-O'Mara & Ryan, 2018).

In addition to such an economic barrier to energy efficiency, the Building Energy Efficiency Survey (BEIS, 2016) also revealed a behavioural barrier: the prioritisation of organisational tasks over energy-related tasks by key stakeholders (Christina et al., 2017). Even though the retail sector has been moving towards a more sustainable future (ARUP, 2017), stakeholders are reported to treat energy-related tasks as an 'add-on' to their existing responsibilities (e.g. customer service) (Christina et al., 2015). Since such a behaviour detrimentally affects both the environmental and economic performance of retail spaces (Nikolaidou et al., 2019), there is an immediate need for triggering the energy-conscious behaviour of stakeholders.

A number of previous studies assessed how organisational structure and staff behaviour to energy use could act as barriers or drivers for energy efficiency in retail building stock (Christina et al., 2014; Christina et al., 2015; Dixon-O'Mara & Ryan, 2018; Sullivan

& Gouldson, 2013; Woods et al., 2017; Galvez-Martos et al., 2013; Bentley, 2016; Klemick et al., 2017; Jiang & Keith Tovey, 2009). Ferreira et al. (2020) investigated the energy intensity (EI) and carbon intensity (CI) of best-performance retailers, as well as their links to policy, strategy, and building practice. The findings of their analysis suggest a holistic approach to corporate culture and social responsibility as a way to reduce CI and EI and mitigate climate change impacts. The authors discussed that in terms of policy, best-performing retailers show a high level of corporate internalisation of environmental management and share a strong top-down management commitment towards sustainability.

Christina et al. (2014) reflected on the links between organisational structure, staff behaviour, and energy efficiency strategy and found that better alignment of user-centre approaches to successful energy-efficient design, operation, and management are key to drive energy savings in stores. Staff behaviour is central to delivering an energy efficiency strategy because effective human interaction is crucial to make new technology and equipment work to specification. Similarly, Woods et al. (2017) argued that although causes of energy use in the retail sector are primarily technical, it is the user behaviour that influences whether actions to reduce energy use are applicable and successful.

An effective energy management system should establish clear and ambitious energy goals (Christina et al., 2015; Ferreira et al., 2020). According to Jiang and Keith Tovey (2009), an effective management system should incorporate both technical and non-technical aspects to energy use and it should be supported at all levels within an organisation. The authors highlighted that energy management systems ought to address issues of governance and ownership. They also demonstrated how raising awareness and behaviour change could support objectives of carbon reduction.

Along with investing in the refurbishment of their stores, retailers hence need to pay attention to the behaviour of their employees and raise their environmental awareness (Galvez-Martos et al., 2013). Adopting such a socio-technical approach can maximise the energy efficiency potential of stores (Guy & Shove, 2000). At the same time, the lack of adequate information on the benefits of such an approach calls for the investigation of behaviours towards energy consumption (Paço & Lavrador, 2017).

Socio-technical approach to energy use

The relationship between technology and society has been conceptualised in many ways: from technological determinism believing that the development of technology follows its own logic and that the technology determines its use (Winner, 1977), to social reductionism or constructionism (Woolgar, 1991) arguing that society and its actors develop the technology they want and use it as they want, implying that technology in itself plays no role. In the 1990s, however, the social constructivist approach became more prominent, focussing on diversity of use among a group of users and displaying use far beyond what was anticipated by the designers (Henderson & Kyng, 1991) and leading to a now widespread agreement that technology both restricts and enables (Orlikowski & Robey, 1991).

A socio-technical approach allows enhancing the understanding of interdependencies and interconnections between technology, work tasks, processes, cultures, and behaviours and explores how the changes in one part of the system affect another (Challenger & Clegg, 2011; Cherns, 1976; Clegg, 2000). It is important to note that in this paper, we specifically draw on the Actor-Network Theory (ANT[1]) (as demonstrated in 'Results and discussion') — however, the research itself is not an ANT study. ANT has been widely used as a frame and mode of thinking about inter-disciplinary energy research in practice. It has become a useful framework for energy research because, as Wong (2016) summarises, it 'expands the purview of analysis to the larger web of people and things that co-constitute energy systems; gives visibility to previously inconspicuous actors and processes; actively engages with ignorance and uncertainty in scientific experimentation; and identifies alternative ways of assembling technologies, people and environments that are fairer and more sustainable' (p. 1). In other words, when employed in energy research, ANT allows for a more networked understanding of large

[1] For readers interested in a broader application of ANT in the context of complexity, see Sage et al. (2011).

technical systems in which the social and technical co-exist and co-evolved in ways that are hard to demarcate (Summerton, 1992; Guy et al., 2015).

Conceptualising sectors of the economy — in our case, supermarket retail space and its role in energy consumption reduction — as socio-technical systems means adopting the 'wider system' view to encompass not only the natural and built components, such as energy resources or a building, but the societal and institutional elements as well, i.e. individuals and organisations (Foxon et al., 2010; Geels, 2005). Bale et al. (2015) note five co-evolving and interacting systems that impact socio-technical system: technologies, institutions, business strategies, user practices, and ecosystems — all leading to an increased degree of complexity in energy system (Hansen et al., 2019). Socio-technical systems are difficult to change radically as this requires change in both established technologies and behaviours. Thus, reducing energy demand will not happen through merely improving individual technologies or changing individual behaviours; instead, it requires interlinked, simultaneous, and potentially far-reaching changes in the systems themselves (Geels et al., 2018).

A socio-technical approach has previously been employed in energy-related studies, for instance, to challenge existing systems in the energy space in order to identify disconnects between technology and behaviours that are systemically supported by the organisational design (Christina et al., 2015, 2017); to analyse energy saving policies (Castree & Waitt, 2017; Giraudet et al., 2011); to model projections for household energy use (Daioglou et al., 2012); or to explore the impact of new technologies and organisational behaviours on energy demand (Geels et al., 2015), to name a few. To date, most of the socio-technical research in energy-related studies on a building scale has focused on domestic use of energy (BRE, 2013; Chui et al., 2014; Kane et al., 2015; Love & Cooper, 2015) and, in particular, on understanding and operationalising thermal comfort (Chappells & Shove, 2005; Guy, 2006; Hitchings, 2009; Shove, 2003a, 2003b, 2006). Various reports and papers offer overviews and critiques of these studies as well as the socio-technical approach in energy-related research (e.g. Geels, 2004, 2019; Hinton, 2010; Wilhite et al., 2014) and it is not our intention to repeat these here.

Little research however exists on using socio-technical approach to explore the energy use in non-domestic sector. Recent studies into socio-technical deployments at schools (New et al., 2019) and independent retail (Kenington et al., 2020) exist highlighting that technical conditions appear to be of considerably less importance than social contexts when it comes to energy consumption reduction, and that many obvious energy reduction opportunities are often ruled out as they do not fit with business or policy priorities. However, this research does not explain how competing priorities compete for attention within non-domestic settings.

Competing priorities and agendas in an agency-constrained environment

In non-domestic environments, the open-plan space requirement for a flexible, service-based economy has rendered the concurrent management of energy demand reduction, along with improved thermo-physiological conditions, particularly problematic. This is due to its 'agency-constrained' users: here, workers have relatively little direct control of their individual environment and have limited capacity to respond to feedback on indoor air quality or thermal comfort within the spaces they work. Moreover, there is a multiplicity of different users of the space. This is particularly the case in retail environments where the interaction of customers creates more variable conditions than office space or other open plan buildings.

Despite accounting for around 3% of UK energy use (Spyrou et al. 2011), addressing energy reduction and optimising thermo-physiological conditions in retail is both under-researched and under-theorised, with most of the research focusing on the specific aspects of the retail sector (e.g. food retail (Braun et al., 2014; Tassou et al., 2011)). Reasons for this are speculative, but goal-setting theory (Locke & Latham, 2002) suggests that specific, difficult goals lead to better performance outcomes than abstract goals where employees feel little ownership or connectivity to the performance improvements intended. With regard to energy savings, this reveals a twofold problem for retail organisations seeking to develop pro-environmental behaviours in their staff: the first concerns the inevitable difficulties in foregrounding secondary goals (i.e. energy consumption which is distal and slow to manifest) with primary goals (i.e. sales which is proximal and immediate); the second is that although most workers interact with energy sources, they rarely personally control a significant amount of consumption themselves. Both factors mean that employees have to be engaged in energy saving in ways that mainstream them as normalised behaviour aligned with key corporate goals. This, in turn, demands tailored strategies for intervention, which account for the prevailing socio-technical system through which energy is consumed within the organisation.

Christina et al.'s (2015, 2017) work provides a clear understanding of what enables and what hinders motivation of the employees in a supermarket setting to reduce the company's energy consumption. Using a retail energy management socio-technical model (Christina et al., 2015, p. 325) built around six elements (namely, organisational culture, energy goals, shop buildings, energy strategy, processes and procedures, and store staff), they demonstrate conflicting perceptions of energy management in the organisation and highlight misconceptions around energy strategies, building management and goals that can be systemically linked to issues around practices and processes. Crucially, they show how goal conflicts can be overcome via a consistent and responsive support system that allows building trust and engagement with staff on the shop floor, and via a practical management strategy enacted through, for instance, job redesign.

Taking into account the environmental and financial impact of employees' behaviour towards energy consumption (Staddon et al., 2016), it is important that such a support system clearly communicates the behaviours that can adversely affect the energy performance of retail outlets. Even in cases where employees have limited direct control of their thermal environment, there are still everyday behaviours that can detrimentally affect energy performance, with energy-unaware behaviour being able to add one-third to the designed energy performance (Nguyen & Aiello, 2013). At the same time, such behaviours can be regarded as energy-saving opportunities that can assist reduction of the energy demand and hence the operational cost and carbon footprint of stores (Richman & Simpson, 2016). Examples of impactful behaviours are leaving the doors on fridge/freezer cabinets open, having ovens on when not necessary (e.g. between baking times or as soon as baking is finished), and leaving back doors open between deliveries (Nikolaidou et al., 2019). Addressing such behaviours requires employee engagement and collaboration as well as customer awareness in order to ensure stores operate to the most efficient manner, saving considerable amounts of energy (Davis & Coan, 2015; Zibarras & Coan, 2015).

Despite the energy-saving potential of behaviours in retail environments, behavioural practice is still under-researched due to the inherent complexity and uncertainty in human behaviour. Behaviour is very different between user environments (e.g. shop floor, shop offices, 'back of the house' storage space). There is still a challenge of making conflicting goals 'visible' in order to incentivise and aid behaviour change and align this with the goals of the company, workers, and customers. The following sections will explore how we combine a techno-economic with the socio-technical analysis in order to bridge this gap.

Methodology

This work is building on the above-mentioned research by Christina et al. (2015, 2017) that focused on adapting a socio-technical framework approach to describing and improving an existing organisational behavioural strategy to support retail energy efficiency. Using a multi-methodological case study approach that includes hard performance data and the qualitative data, we take this work further in order to explicate the socio-technical context within which energy consumption is considered by various actors in an agency-constrained environment — a large supermarket, where actors have different behaviour and priorities. In particular, this study incorporates a broader constituency of stakeholders who have the decision-making power, establishing ways of bringing a disparate array of stakeholders together around the energy consumption agenda.

A longitudinal case study carried out over 24 months was based on the socio-technical meta-principles, acknowledging that any store design is systemic, that all parts of a system are inter-connected, and that values and mind sets are integral to design (Clegg, 2000). The longitudinal approach was designed in order to engage with a wide range of actors that directly or indirectly impact energy consumption in a large supermarket and to consequently design a mixed reality design platform (MRDP, described later in this section) that represents this agent-constrained environment and allows to trace how decisions are made and trade-offs achieved (or not) when it comes to competing priorities and agendas. A total of 25 participants (including 13 in-store employees, 4 architects, and 8 HQ senior management team members) took part in either semi-structured interviews or focus groups during the period 2017 to 2019. The case study comprised a raft of activities, organised in three phases, with each phase informing the following phase:

During *phase 1*, all contexts of the energy consumption in a large supermarket store were included by developing an energy consumption database. This database was populated by predictions of energy consumption from a dynamic energy simulation model for a wide range of scenarios, providing a quantitative link between plausible design scenarios and the corresponding energy performance of the supermarket. The geometry and construction were informed by the building information model (BIM) that was provided by the retail company. Model assumptions about operation and equipment reflect the information that was supplied by the company and emerged from the interviews with their employees (interview outcomes are presented in 'Energy consumption influencers'), therefore capturing details of the equipment (e.g. freezers, ovens) found in store. Creating the energy model and running several simulations, each capturing unique energy consumption profiles about one aspect of the supermarket performance, quantified the opportunities for reducing the energy consumption of the supermarket. These energy-saving opportunities informed the development of scenarios for the MRDP, which were then explored by energy experts employed by the company, with the MRDP thus enabling both the quantitative and qualitative assessments of the supermarket.

Using *content analysis*, we explored the company's energy consumption reduction strategies and policies have been carried out to understand what the corporate priorities are and how they have evolved over time. The analysis was carried out inductively, in order to reveal the spectrum of energy-related themes covered in strategy and policy documents as well as the approaches that are implemented in stores in order to encourage the employees to save energy. The results of the policy content analysis informed the questions for the interviews.

Two 2-h *transect walks* (one during a peak time and one during an off-peak time) with the store manager were carried out in order to observe the daily operation of the store, both on the shop floor and at the 'back of the house' and to familiarise ourselves with the space of the retail store. These observations informed the interview questions as they helped refine the store operation narrative (see 'Results and discussion'); they also informed the scenario (layout) design.

Semi-structured interviews with 13 supermarket employees were carried out in the supermarket; these included a wide variety of staff such as the store manager, the store engineer, non-food senior manager, the manager and a general assistant, the clothing manager and a general assistant, a baker, a fish and meat counter assistant, a checkout area manager, a self-checkouts manager, and a customer services manager. Each interview lasted approximately 20 min during the employees' break. The participants were asked questions about their daily activities, the perceptions of their role in reducing the store's energy consumptions, and the incentives and barriers for reducing energy consumption.

Phase 2 focused on building the MRDP and its scenarios, informed by phase 1:

In order to realistically represent the design of a large retail store, four *interviews with architects* who work in a retail design have been carried out. These informed some of the zoning layouts and spatial permutations later used as a workshop — and allowed us to reflect on the complexity of a retail space in that it needs to combine convenience, efficiency, profitability, and other elements. The company's current process of discussing these trade-offs primarily uses 2D plan drawings which can limit the spatial understanding in comparison to an interactive and immersive environment. While it is not the intention of this paper to discuss the complexities that design of the retail space poses, it is understood that a focus on the design process and result of a specific store could provide more nuanced findings; however, the interviews along with the company's spatial principles guided the store layout and scenarios explored for this proof-of-concept study.

A '24 h in a life of a store' timeline *narrative* was built in order to demonstrate how the energy consumption changes depending on a day, time of the day, or a season, and what are the impacts of

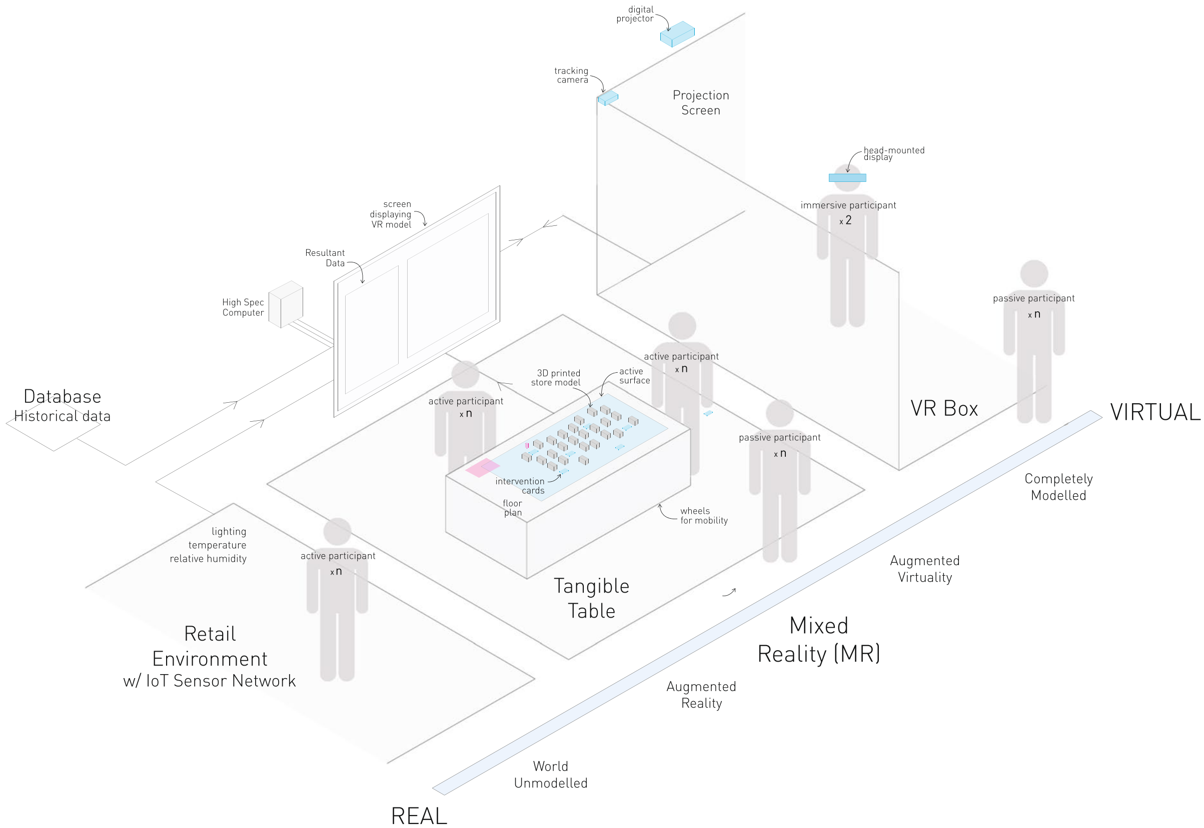

Fig. 1 Mixed reality design platform system as applied to this project

various human and non-human actants on energy consumption. The intended and unintended consequences of various activities in a store as well as the intended and unintended outcomes of the company's energy policy were then *mapped out* drawing on the Actor-Network Theory (noted in 'Results and discussion').

A *focus group* with the employees of the headquarters, including six members from the energy management team and one from the store planning team, was carried out in order to reality-check the results from the above-mentioned datasets. The group's broad experience provided additional insights into specific problem areas in the stores regarding energy use and the strategies and solutions trialled with varying success. This provided additional material to review and contextualise the socio-technical context.

The MRDP was constructed during this phase consisting of four main modules, namely virtual reality headset with gesture-controller (VR system), multiple user shared virtual reality environment, tabletop fiducial marker tracking system, and scaled model and widgets as tangible user interface. Fig. 1 diagrams the MRDP system and the data flow for this application.

The data communication between the VR system and the multiple-user tangible interface was established through game engine-based local networking. Given the large area needed to model the retail environment and the complex customised interactive tasks to be conducted, a custom tangible table was designed and fabricated for engaging multiple stakeholders; see Fig. 2. The fiducial marker tracking system is implemented with a DIY A0 size infrared lightbox embedded with an infrared camera with daylight filter and a short throw projector. The scaled interior model of the retail store and small widgets used with the tangible interface were made with a 3D printer.

HTC Vive was selected for the VR system and a large 60-in. Philip touch-screen monitor is used

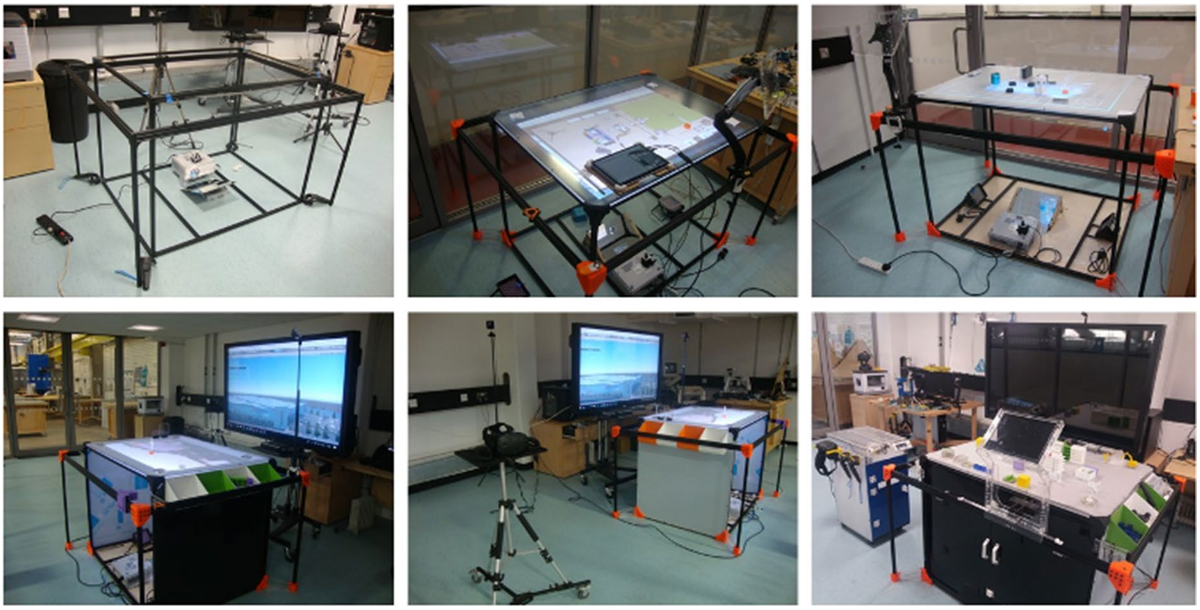

Fig. 2 Development of custom tangible table for MRDP system

for shared virtual reality display. Unity, a real-time development platform, was used as the main interface for the shared virtual reality environment, interactions are scripted in C#, the 3D model was built in Autodesk Revit, and energy data were fed in from DesignBuilder and EnergyPlus. The MRDP system came together as a unified tool to help us establish ways of thinking about space and its purpose as it relates to energy consumption.

Phase 3 was used to validate our findings through a 1-day workshop with four energy experts employed by the company. The workshop was built around the use of the MRDP and comprised two high-level scenarios (zones and agents):

1. Zone-based scenario: Participants were provided with a simplified floor plan of a metro store divided into a grid layout as shown in Fig. 3; the cell positions of items including the entrance and checkout were informed by the transect walks and interviews. The first task was to simply get participants familiar with the table; they were asked to move items to improve the overall shopping experience only considering personal preferences.

To do this, a set of basic rules and tools were provided, e.g. each item had a pole widget they could move around and for this first exercise, all items were to remain and there could only be one item in each cell (see Fig. 4).

As a follow-on task, participants were then asked to consider how their proposed layout would change considering two variables: convenience and energy consumption. The convenience factor broke the store down into four zones based on the entrance and checkout locations, while the energy factor broke the store down into three zones — 'outer', 'inner', and 'door' (see Fig. 5). This was based on simple observations from the transect walks: (a) refrigeration is lined along the wall and (b) doors tend to stay open allowing increase air exchange.

For this task, participants were given more freedom to add new items, remove items, duplicate items, and put up to two items in a cell. In addition, a new widget (a green cube) was introduced that would switch on and off a visualisation that simulated a real-time score for each item based on its location in the store. The total score was visualised as a bar with energy (blue) and convenience (green) making up a portion, respectively. For example, a refrigerated item

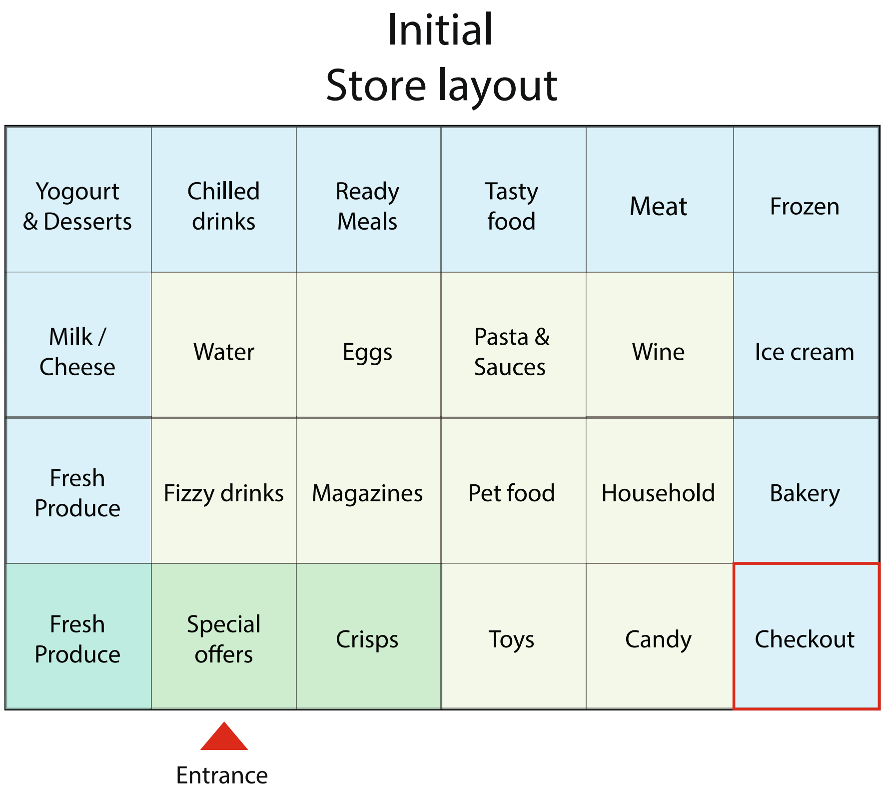

Fig. 3 Initial location of items in a store

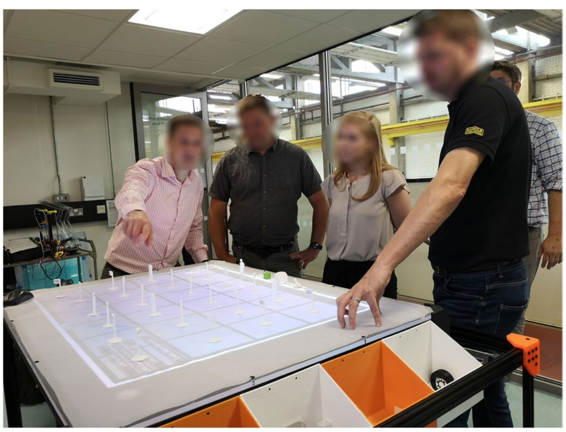

Fig. 4 Energy experts engaging with zonal store configuration

would have a higher energy score in the door zone than the outer zone. A proposed store configuration could then be given an aggregate score based on totalling all the cells. This activity allowed participants to engage in a dialogue about basic store layout and discuss trade-offs of locating items based on defined criteria (i.e. energy and convenience). This allowed us to observe how priorities were discussed and decisions made (Fig. 6).

2. Agent-based scenario: Participants worked together to change the design of a virtual store. They took turns immersing themselves into the virtual store with the VR headset, discussing the experience with the other participants who were able to adjust eight design parameters via widgets on the tangible table (dials and sliders): size of window; transparency of window; wall colour; ceiling height; light fixtures; light intensity; floor colour; and door size (Fig. 7).

The participant with the VR headset was tasked to carry out one of two roles, each having a distinct set of tasks (staff or customer) — as seen in Fig. 8. For example, staff was required to restock shelves, close refrigerator, and change a ceiling lamp while the customer was given a shopping list that they had to collect. The roles and tasks helped contextualise the impact of the design changes as discussed and implemented. Participants around the tangible table

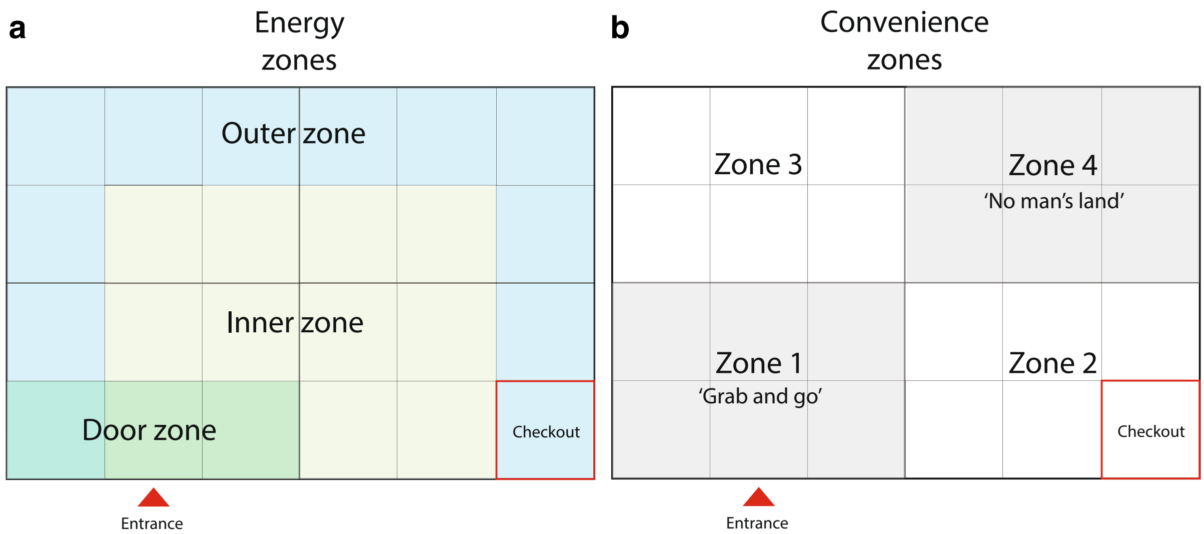

Fig. 5 Decomposition of grid based on energy (left (**a**)) and convenience (right (**b**))

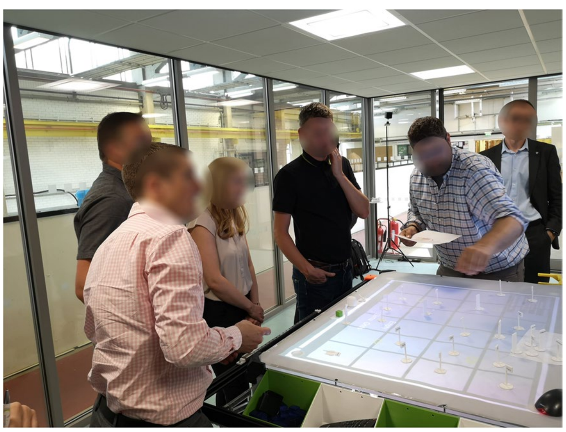

Fig. 6 Energy experts moving widgets and discussing trade-offs

were given the power to implement new tasks. This activity captured the effects of different store designs and arrangements through working and shopping scenarios on energy consumption. It allowed participants to immerse themselves in proposed changes in real-time and to discuss the impact and trade-offs between proposed changes resulting in uniquely different design configurations. Because of limitations, real-time energy simulations were not ran for the different design configurations.

Given the mixed-methods nature of the research, an abductive approach towards data analysis was employed allowing building our theories as our data were gathered. Each dataset was analysed separately, informing the next steps. All interviews and focus groups were semi-structured in order to generate data that were not tied to existing hypotheses or theory; these were recorded and transcribed and then analysed, reflecting on the relevance of the findings. The workshop was recorded and the screenshots that demonstrate changes in decision makers were captured.

The themes of the data analysis were not pre-determined. This approach enabled building an integrated themed dataset that was reflective of different parts of the organisation as well as external datasets. Instead, themes were generated and adapted across all the discrete datasets created through sessions with different participants and different collection dates across the length of the study. The integration of data from varied sources around themes is reflective of the socio-technical worldview of systemic interconnectivity that was adopted for this study.

Results and discussion

Energy consumption influencers

As noted in the previous section, a 'Day in a lifetime of a store' timeline narrative (Table 1) around the

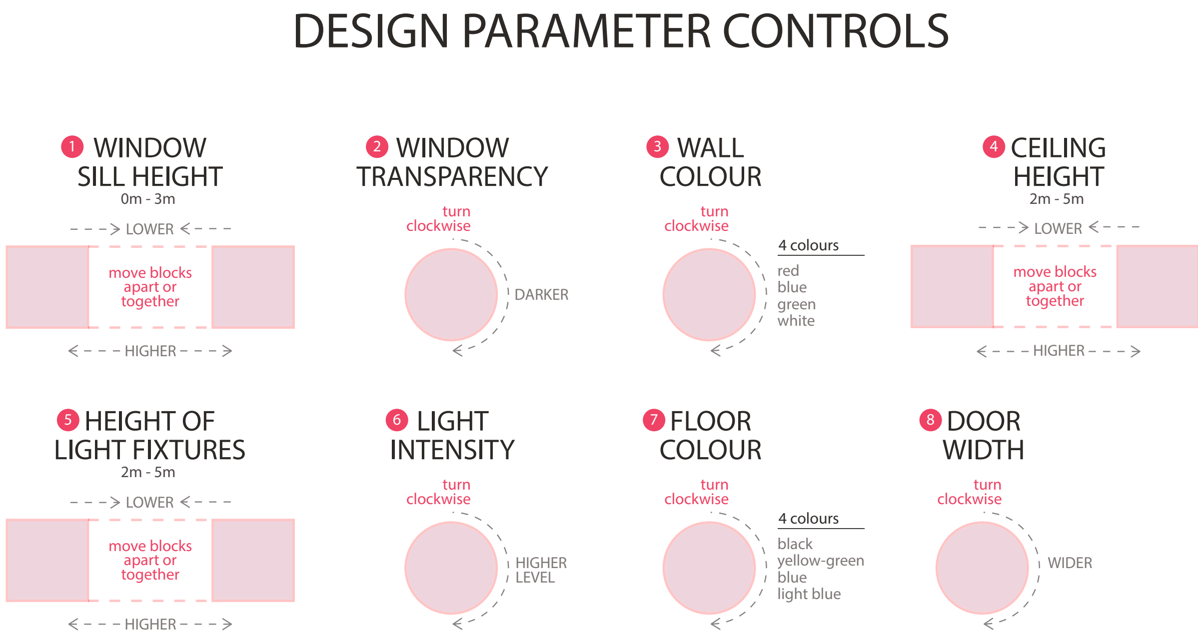

Fig. 7 Diagram for controlling each of the design parameters

Fig. 8 Photos showing participants engaging in the activity

Table 1 A day in a lifetime of a store timeline representing generic temporal energy consumption influencers

Time[1]	Weekday (Monday to Friday)	Weekend (Saturday)	Sunday
8am	Lights on – all faults become obvious (e.g. not all light came on)	Lights on – all faults become obvious (e.g. not all light came on)	Store closed Baking starts at about 7am on a Sunday and is only done once
9am			
10am	Bakery off (first lot of baking done for the day)	Bakery off (first lot of baking done for the day)	
11am	Measuring temperature in the store	Measuring temperature in the store	Bakery off
12 noon			
1pm	Bakery on – second bake of the day	Bakery on – second bake of the day	
2pm			
3pm			
4pm	Bakery off – second baking of the day is complete	Bakery off – second baking of the day is complete	Store closed Stocking still taking place but with the reduced number of staff
5pm			
6pm			
7pm			
8pm			
9pm			
10pm			
11pm	Lights off to 60% of the usual lighting level Heating goes off		
Midnight			
1am			

[1]Light green indicates peak times in terms of customers. Light blue indicates time when most shelves are stocked and deliveries are taking place

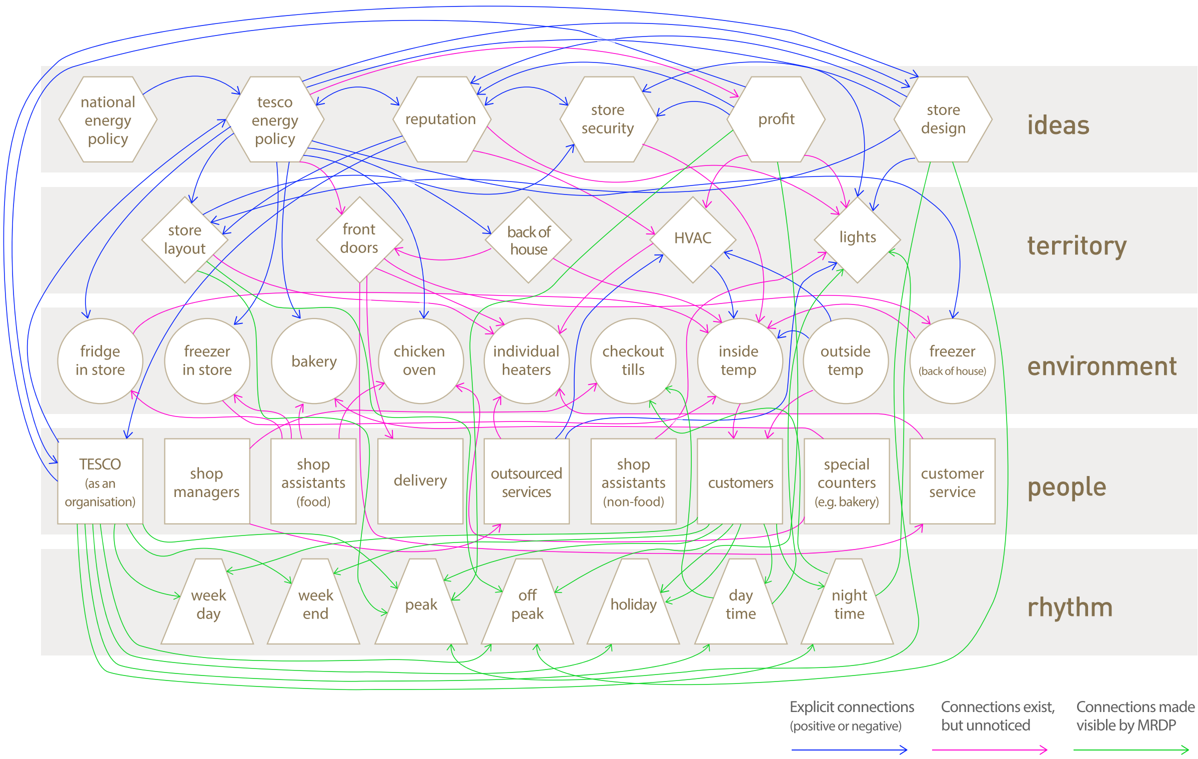

Fig. 9 The relationship between human and non-human energy consumption influencers

operation of the store has been created as a scaffold to understand the influencers of energy consumption which may not have been obvious otherwise.

The timeline revealed several elements that impact energy consumption:

- In-store thermal comfort: after the observations and the interviews, it became apparent that the store has very little control over the most energy-consuming elements, such as heating and cooling, or lighting; the control of these is outsourced to a company that monitors and adjusts the energy performance. In some cases, this leads to additional energy consumption: for instance, staff at the customer services desk located next to the main entrance would use an electric heater if it is cold outside and the doors open frequently.
- In-store energy consumption: there are however elements in the store that are controlled by the employees. For instance, the ovens must be switched off once the required number of chickens are grilled; however, ovens often stay on until someone would switch them off in the of the day (or not at all).
- Daily patterns: Fridays and Saturday (and in particular 'Five star' weekends, i.e. those just before a holiday) are considered to be the busiest days, and they differ significantly from a weekday operation of the store as there is a constant high flow of customers throughout the day and in the evening. Consequently, the shelves are restocked more frequently (particularly those where seasonal items are) — and it is important to note that both understocked and overstocked fridge shelves have an impact on the efficiency of energy consumption; and thus, a store employee could potentially play a role in reducing it.

The relationship between energy consumption influencers

Once explored, the energy consumption influencers were then assembled to reveal the expected and unexpected relationship between human actions, company policy, store design, and other influencers and to identify an array of interacting elements. A starting point for mapping out the elements was to identify the stakeholders and a range of non-human actants, as well as the ideas that are shaping energy consumption. Following from the elements identified through the narrative, the relationships between five following themes (and the elements within these) were mapped out (Fig. 9):

- The 'territory' — the constants that cannot be changed by the employees in the store, e.g. store's layout, front doors, back of the house usage, lighting, and HVAC;
- The 'environment' — changeable elements that affect internal energy use, e.g. freezers and fridges, baking equipment, checkout tills, individual heaters as well as temperature inside and outside;
- The 'rhythm' — seasonal fluctuations (e.g. festivals); daily patterns (e.g. peak times), holidays, working hours;
- The 'people' — customers, managers, staff, 'outsourcers', delivery, the retail organisation itself;
- The 'ideas' — national and corporate policy, reputation, sustainability, profit, organisational culture.

Mapping out the five themes explored how the boundaries of each theme could affect energy consumption in multiple, overlapping, and sometimes unexpected, ways. Fig. 9 shows key relationship between various elements within the store, thus allowing us to ascertain constraints and user agency. Here, the simplest is the technical aspects of the 'territory' and the 'environment' in the context of the store operation; it is expected that these elements are directly or indirectly connected to the energy consumption. The map however reveals their connection with the social elements such as choices and practices, and the unintended consequences of the interaction *within* and *between* 'the environment' and 'the people'. Whilst the most energy-related elements are locally bounded at a store scale, the map shows that they could also be 'projected' outwards, towards the 'Ideas' theme.

Understanding the relationship reinforced that whilst energy consumption in the retail sector is often discussed as a stable technological system, it is actually shaped into a final form by social actions and inactions and higher level non-technical interests. The tangible table was then used as a tool that helps us establish the ways of thinking and visualising these interactions and space whilst maintaining the focus on energy consumption.

Decision making 'in the box' (scenarios — zones)

The identification of the bias and perceptions that drive an individual store allows to understand what priorities in an agent-constrained environment are salient and how the decisions that are informed by these priorities impact the store's design, operation, and, consequently, energy consumption. Overall, the discussion and decisions around the layout were mostly driven by factors that are influenced by practices, problems, and choices and the speed of purchase, location and availability of building services (e.g. piping and sockets), food type (e.g. hot and cold should be as far from each other as possible), encouragement of spontaneous purchase (e.g. daily purchases like milk should be at the back of the store), built-in costs, and profitability. The workshop with energy experts from the retail company thus revealed the following competing priorities and agendas that influence consideration of energy consumption:

- *Energy consumption vs. convenience*: Convenience is about simplifying and enhancing the shopping experience— it determines where, when, why, what, and how — and is implicitly linked to profit. Convenience is a subjective characteristic (e.g. what may be perceived as a 'convenient' location of a particular shopping item by one person may not be 'convenient' for another). The participants have debated around convenience extensively and were indecisive. Whilst they felt it would be convenient to have fruit and vegetable at the entrance, they also agreed that such proximity to the outside environment (e.g. sunlight, hot/cold temperatures) would have a negative impact on the produce. Another suggestion was to put bakery at the front as the customers may find the smell attractive — but in this case, the participants felt there might be implications for the energy consumption. It was then suggested that putting the newspaper stand next to the door is energy efficient (as the temperature is not important for magazines) but at the same time, it may not be as attractive. In addition, newspapers/magazines are often a spontaneous purchase that often occurs whilst people are waiting at the checkout.

- *Energy consumption vs. professional bias*: Here, the participants' decision about the layout was affected by their daily roles. For instance, an engineer suggested that the location of the energy-consuming furnishing should be co-located with the infrastructure; for instance, it was suggested to put all fridges at the back of the store as all the pipes are there. Participants also suggested that cold and frozen items should not be next to bakery as this increases the energy consumption; instead, fridges, delicatessen section, frozen food, and ready meals as well as meats should all be co-located in order to reduce the energy consumption. This also made sense from an energy perspective: fridges should be at the back of the store, where it is possible to turn the heating off. The professional priority however often clashed with personal bias and convenience. Moreover, there was a feeling of redundancy as participants acknowledged that it does not really matter how they arrange the design as the main energy-saving elements (air conditioning, heating, lighting) are controlled externally, and it is perceived that not much can be done in a store.
- *Energy consumption vs. profit*: When arranging the zones, the participants often discussed how one or the other layout would stimulate the sales. This is not surprising as in the retail environment, profit is the largest operational priority; thus, the primary role of an employee is to ensure quick turnaround and response that positively affect performance of a store. The participants suggested that daily items (such as milk) could be located at the back of the store as this would force shoppers to walk through the store and potentially could encourage them to buy other things. This suggestion clashed with convenience but created a synergy with co-location of the fridges next to pipes. The participants also discussed whether energy consumption is on the agenda for those working on the shop floor and who could, in principle, have some control over the energy consumption (e.g. by closing fridge doors or turning the ovens off when not in use). Whilst the company sees energy as something that can contribute to profit (as the reduction in consumption would lead to lower energy bills), it does not always translate into the operation (due to the lack of personal motivation — see next point). The daily staff meetings focus on profit-making and although there are occasionally bursts of energy-saving initiatives, they get forgotten too fast.
- *Energy consumption vs. personal bias and motivation*: Personal bias was closely linked to convenience. For instance, one of the participants noted that the toys section is perhaps not needed in the store, instead more fruits and vegetables could be displayed. When discussing personal preferences, energy consumption was not featured in the conversation. The participants also acknowledged that from the employees' perspective, organisational culture and organisational policies and commitments that target energy consumption do not always fit with their commitments, as there is a lack of personal motivation. For instance, energy savings in a household are often driven by a reduction in financial costs; in the case of retail, whilst it is understood that the energy savings contribute to organisation profitability, there is little motivation for the non-managers to care about this. One participant noted that if energy saving is linked to a bonus (e.g. when the retailer makes profit, every employee gets a bonus) or if they know that by closing a fridge door they would save £X, which would contribute to profit and therefore bonus — and there were constant reminders about it — it would encourage them to close a fridge door. Contributions towards energy savings are not reflected in any performance reviews; there is very little training (apart from a mention during the induction); in addition, most of the initiatives are advertised at the offices, where the employees hardly spend any time at all.

Every priority outlined above came up in the layout discussions several times — and these were competing not just with the decisions about the energy consumption reduction, but also with each other.

Conclusions

This paper explored the socio-technical context within which energy consumption is considered by various actors in a large supermarket given. It demonstrated the 'social ordering of choices, problems and practice' by unveiling that actors' behaviour driven by convenience or profit takes a priority in decision making and highlighting that the retail environment is agency-constrained (i.e. shoppers or employees can hardly do anything individually to affect energy consumption). These tensions however are usually explored through either technical quantitative studies or behavioural qualitative studies. We wanted to make this challenge more visible. Using an experimental methodical approach — which was possible using a 'tangible table' — we showed how it can aid decision-making mechanisms by not only encouraging exchanges but also, most importantly, highlighting contradictions, which leads actors to find a consensus or instead to identify points of opposition that are impossible to overcome.

By moving between virtual and real space/time, the authors were able to remove the conventional constraints associated with both approaches; we were able to visualise conflicts and dependencies between employees and energy interventions, i.e. various elements of socio-technical system. Such visualisation is important because it enables a clearer focus on the socio-technical system allowing for a clearer understanding of how interventions and decisions come together, which would be impossible at full scale. In other words, the key contribution of the technology is the implementation of multiple experiences.

The decisions related to energy reduction in the retail sector rely heavily on oral communication between the decision-makers and the employees and the shoppers, with the assistance of pictures and brief documents. However, because of the agency-constrained nature of the retail environment that spans across multiple working phases and involves multiple parties, it is difficult for participants to clearly grasp the whole picture of energy consumption and its influencers and to make accurate decisions about its reduction.

One of the main benefits of creating a platform that allows to embrace a socio-technical context of the retail space is clearer understanding on interventions. The visualisation of socio-technical interactions can also help in visualising the decisions on where interventions could be made, what needs to be considered, and how this differs from different perspectives. Priorities that often remain 'unspoken' become visible — and thus provide a powerful foundation for the discussion about the consequences of an intervention there, and then thus reduce the complexity of discussions and keep crucial information available during the entire discussion process.

Technologies such as the tangible table could provide a middle ground for decision making that reflects socio-technical context that reflects not only the retail spaces but also its temporality. Here, the decisions are being made 'tangible': having an object that represents a decision that leads to an intervention at hand is important as it speeds up the process of decision making and helps participants focus on social and technical elements simultaneously. Being able to immerse in a socio-technical visual representation of a supermarket creates a common ground for everybody and bridges the gap between different understandings and/or interests of different stakeholders. It supports different stakeholders in a constructive dialogue, providing structure to various interventions through a set of informed rules that in a way become a driving force in the dialogue rather than restricting creativity.

Acknowledgements Removed to protect anonymity of the authors – to be added after the peer review

Declarations

Conflict of interest The authors declare no competing interests.

References

Acha, S., Mavromatidis, G., Caritte, V., and Shah, N. (2013). Effective low-cost energy saving strategies in supermarkets: An UK case study. *In*: *ECOS 2013*. 16–19.

ARUP (2017). Future of retail. Available at: https://www.arup.com/perspectives/publications/research/section/the-future-of-retail-2017. Accessed 20 Dec. 2020

Bale, C. S. E., Varga, L., & Foxon, T. J. (2015). Energy and complexity: New ways forward. *Applied Energy, 138*, 150–159.

Bentley, Y. (2016). UK company strategies in reducing carbon dioxide emissions. *International Journal of Business and Economic Development, 4*(*2*), 78.

Braun, M. R., Altan, H., & Beck, S. B. M. (2014). Using regression analysis to predict the future energy consumption of a supermarket in the UK. *Applied Energy, 130*, 305–313.

BRE. (2013). *Energy follow up survey*. BRE.

Business Energy and Industrial Strategy (2016). Building energy efficiency survey. Available at: https://www.gov.uk/government/collections/non-domestic-buildings-energy-use-project. Accessed on 15 Dec. 2020

Castree, N., & Waitt, G. (2017). What kind of socio-technical research for what sort of influence on energy policy? *Energy Research and Social Science, 26*, 87–90.

Challenger, R., & Clegg, C. W. (2011). Crowd disasters: A socio-technical systems perspective. *Contemporary social science, 6*, 343–360.

Chappells, H., & Shove, E. (2005). Debating the future of comfort: Environmental sustainability, energy consumption and the indoor environment. *Building Research and Information, 33*, 32–40.

Cherns, A. B. (1976). The principles of sociotechnical design. *Human Relations, 29*, 783–792.

Christina, S., Dainty, A. R. J., & Daniels, K. (2014). How organisational behaviour and attitudes can impact building energy use in the UK retail environment: A theoretical framework. *Architectural Engineering and Design Management, 10*(*1-2*), 164–179.

Christina, S., Waterson, P., Dainty, A., & Daniels, K. (2015). A socio-technical approach to improving retail energy efficiency behaviour. *Applied Ergonomics, 47*, 324–335.

Christina, S., Dainty, A., Daniels, K., Tregaskis, O., & Waterson, P. (2017). Shut the fridge door! HRM alignment, job redesign and energy performance. *Human Resource Management Journal, 27*(*3*), 382–402.

Chui, L. F., Lowe, R., Raslan, R., Altamirano-Medina, H., & Wingfield, J. (2014). A socio-technical approach to post-occupancy evaluation: Interactive adaptability in domestic retrofit. *Building Research and Information, 42*(*5*), 574–590.

Clegg, C. W. (2000). Socio-technical principles for system design. *Applied Ergonomics, 31*, 463–477.

Daioglou, V., van Ruijven, B. J., & van Vuuren, D. P. (2012). Model projections for household energy use in developing countries. *Energy, 37*, 601–615.

Davis, M. C., & Coan, P. (2015). Organizational change. In J. Robertson & J. Barling (Eds.), *The psychology of green organizations*. Oxford University Press.

Delzendeh, E., Wu, S., Lee, A., & Zhou, Y. (2017). The impact of occupants' behaviours on building energy analysis: A research review. *Renewable and Sustainable Energy Reviews, 80*, 1061–1071.

Dixon-O'Mara, C., & Ryan, L. (2018). Energy efficiency in the food retail sector: Barriers, drivers and acceptable policies. *Energy Efficiency, 11*(*2*), 445–464.

Elbeltagi, E., Wefki, H., Abdrabou, S., Dawood, M., & Ramzy, A. (2017). Visualized strategy for predicting buildings energy consumption during early design stage using parametric analysis. *Journal of Building Engineering, 13*, 127–136.

Ferreira, A., Pinheiro, M. D., de Brito, J., & Mateus, R. (2020). Relating carbon and energy intensity of best-performing retailers with policy, strategy and building practice. *Energy Efficiency, 13*(*4*), 597–619.

Fieldson, R., & Rai, D. (2009). An assessment of carbon emissions from retail fit-out in the United Kingdom. *Journal of Retail and Leisure Property, 8*(*4*), 243–258.

Foxon, T. J., Hammond, G. P., & Pearson, P. J. G. (2010). Developing transition pathways for a low carbon electricity system in the UK. *Technological Forecasting and Social Change, 77*, 1203–1213.

Galvez-Martos, J. L., Styles, D., & Schönberger, H. (2013). Identified best environmental management practices to improve the energy performance of the retail trade sector in Europe. *Energy Policy, 63*, 982–994.

Geels, F. W. (2004). From sectoral systems of innovation to socio-technical systems: Insights about dynamics and change from sociology and institutional theory. *Research Policy, 33*, 897–920.

Geels, F. W. (2005). *Technological transitions and system innovations: A co-evolutionary and socio-technical analysis*. Edward Elgar.

Geels, F. W. (2019). Socio-technical transitions to sustainability: A review of criticisms and elaborations of the Multi-Level Perspective. *Current Opinion in Environmental Sustainability, 19*, 187–201.

Geels, F., Schwanen, T., & Sorrell, S. (2015). *The socio-technical approach to low-energy innovation*. CIED Available at: http://cied.ac.uk/files/file.php?name=cied-research-strategy.pdf&site=440

Geels, F., Schwanen, T., Sorrel, S., Jenkins, K., & Sovacool, B. K. (2018). Reducing energy demand through low carbon innovation: A sociotechnical transitions perspective and thirteen research debates. *Energy Research and Social Science, 40*, 23–35.

Gerdeman, D. (2007). Designed to sell. *Contract, 49*, 78–79.

Gimeno-Frontera, B., Mainar-Toledo, M. D., de Guinoa, A. S., Zambrana-Vasquez, D., & Zabalza-Bribián, I. (2018). Sustainability of non-residential buildings and relevance of main environmental impact contributors' variability. A case study of food retail stores buildings. *Renewable and Sustainable Energy Reviews, 94*, 669–681.

Giraudet, L.-G., Guivarch, C., & Quirion, P. (2011). Comparing and combining energy saving policies: Will proposed residential sector policies meet French official targets? *Energy Journal, 32*(*1*), 213–242.

Guy, S. (2006). Designing urban knowledge: Competing perspectives on energy and buildings. *Environment and Planning. C, Government & Policy, 24*, 645–659.

Guy, S., & Shove, E. (2000). *The sociology of energy, buildings and the environment: Constructing knowledge, designing practice*. Routledge.

Guy, S., Sherriff, G., Chmutina, K., & Goodier, C. I. (2015). Assembling energy futures: Seawater district heating in the Hague, Netherlands. In Y. Rydin & L. Tate (Eds.), *Materiality and planning: Exploring the influence of actor-network theory* (pp. 142–156). Routledge.

Hansen, P., Xiu, L., & Morrison, G. M. (2019). Agent-based modelling and socio-technical energy transitions: A systematic literature review. *Energy Research and Social Science, 49*, 41–52.

Henderson, A., & Kyng, M. (1991). There's no place like home: Continuing design in use. In J. Greenbaum & M. Kyng (Eds.), *Design at work: Cooperative design of computer artefacts* (pp. 219–240). Lawrence Erlbaum.

Hinton, E. (2010). *Review of the literature relating to comfort practices and socio-technical systems. (Environment, Politics and Development Working Paper Series, 35)*. King's College London Available at: https://eprints.soton.ac.uk/342182/

Hitchings, R. (2009). Studying thermal comfort in context. *Building Research and Information, 37*, 89–94.

Iyer, S. R., Sankar, M., Ramakrishna, P. V., Sarangan, V., Vasan, A., & Sivasubramaniam, A. (2015). Energy disaggregation analysis of a supermarket chain using a facility-model. *Energy and Buildings, 97*, 65–76.

Jenkins, D. P. (2008). Using dynamic simulation to quantify the effect of carbon-saving measures for a UK supermarket. *Journal of Building Performance Simulation, 1*(*4*), 275–288.

Jiang, P., & Keith Tovey, N. (2009). Opportunities for low carbon sustainability in large commercial buildings in China. *Energy Policy, 37*(*11*), 4949–4958.

Kane, T., Firth, S. K., & Lomas, K. J. (2015). How are UK homes heated? A city-wide, socio-technical survey and implications for energy modelling. *Energy and Buildings, 86*, 817–832.

Kenington, D., Chiu, L. F., Janda, K. B., & Ruyssevelt, P. (2020). Encouraging energy efficiency in united kingdom independent retail? The case of the butcher, fishmonger and cycle-shop. *Energy Research and Social Science, 62,* Article 101347. https://doi.org/10.1016/j.erss.2019.101347.

Klemick, H., Kopits, E., & Wolverton, A. (2017). Potential barriers to improving energy efficiency in commercial buildings: The case of supermarket refrigeration. *Journal of Benefit-Cost Analysis, 8*(*1*), 115–145.

Kolokotroni, M., Tassou, S. A., & Gowreesunker, B. L. (2015). Energy aspects and ventilation of food retail buildings. *Advances in Building Energy Research, 9*(*1*), 1–19.

Kolokotroni, M., Mylona, Z., Evans, J., Foster, A., & Liddiard, R. (2019). Supermarket energy use in the UK. *Energy Procedia, 161*, 325–332.

Locke, E. A., & Latham, G. P. (2002). Building a practically useful theory of goal setting and task motivation. A 35-year Odyssey. *American. Psychology, 57*(*9*), 705–717.

Love, J., & Cooper, A. (2015). From social and technical to socio-technical: Designing integrated research on domestic energy use. *Indoor and Built Environment, 24*(*7*), 986–998.

Mylona, Z., Kolokotroni, M., & Tassou, S. A. (2017). Frozen food retail: Measuring and modelling energy use and space environmental systems in an operational supermarket. *Energy and Buildings, 144*, 129–143.

Mylona, Z., Kolokotroni, M. and Tassou, S. A. (2018). A study of improving energy efficiency of small supermarkets by modelling interactions between building, HVAC, refrigeration and display product. *Refrigeration Science and Technology*, 44–52

New, K., Devine, J., Woodcock, T., Beck, S., Finney, J., Hazas, M., Banks, N., Smith, K., & Bailey, T. (2019). *Energy in schools: Promoting global change through socio technical deployments*. Proceedings of the Living in the Internet of Things Conference.

Nguyen, T. A., & Aiello, M. (2013). Energy intelligent buildings based on user activity: A survey. *Energy and Buildings, 56*, 244–257.

Nikolaidou, E., Yu, Y., Schmidt-III, R., Dainty, A., Cook, M., Chmutina, K., and Marini, D. (2019). 'Inside the box': A cooperative game for co-creating energy efficient retail spaces. *In*: *BS2019, 16th Conference of International Building Performance Simulation Association*.

Orlikowski, W. J., & Robey, D. (1991). Information technology and the structuring of organizations. *Journal of Information Systems Research, 2*, 143–169.

Paço, A., & Lavrador, T. (2017). Environmental knowledge and attitudes and behaviours towards energy consumption. *Journal of Environmental Management, 197*, 384–392.

Pérez-Lombard, L., Ortiz, J., & Pout, C. (2008). A review on buildings energy consumption information. *Energy and Buildings, 40*(*3*), 394–398.

Pothithou, M., Hanna, R. F., & Chalvatzis, K. J. (2016). Environmental knowledge, pro-environmental behaviour and energy savings in households: An empirical study. *Applied Energy, 184*, 1217–1229.

Richman, R., & Simpson, R. (2016). Towards quantifying energy saving strategies in big-box retail stores: A case study in Ontario (Canada). *Sustainable Cities and Society, 20*, 61–70.

Sage, D., Dainty, A., & Brookes, N. (2011). How actor-network theories can help in understanding project complexities. *International Journal of Managing Projects in Business, 4*(2), 274–293.

Schönberger, H., Galvez Martos, J. L., & Styles, D. (2013). Best environmental management practice in the retail trade sector, learning from frontrunners, European Commission. *Joint Research Centre, Institute for Prospective Technological Studies*. https://doi.org/10.2791/1775

Shove, E. (2003a). *Comfort, cleanliness and convenience: The social organisation of normality*.

Shove, E. (2003b). Converging conventions of comfort, cleanliness and convenience. *Journal of Consumer Policy, 26*, 395–418.

Shove, E. (2006). Efficiency and consumption: technology and practice. In T. Jackson (Ed.), *The Earthscan reader in sustainable consumption*. Earthscan.

Spyrou, M. S., Shanks, K., Cook, M. J., Pitcher, J., & Lee, R. (2014). An empirical study of electricity and gas demand drivers in large food retail buildings of a national organisation. *Energy and Buildings, 68*, 172–182.

Staddon, S. C., Cycil, C., Goulden, M., Leygue, C., & Spence, A. (2016). Intervening to change behaviour and save energy in the workplace: A systematic review of available evidence. *Energy Research & Social Science, 17*, 30–51.

Sullivan, R., & Gouldson, A. (2013). Ten years of corporate action on climate change: What do we have to show for it? *Energy Policy, 60*, 733–740.

Summerton, J. (1992). *District heating comes to town: The social shaping of an energy system*. Linköping University.
Sweeney, J. C., Kresling, J., Webb, D., Soutar, G. N., & Mazzarol, N. T. (2013). Energy saving behaviours: Development of practice-based model. *Energy Policy, 61*, 371–381.
Tassou, S. A., Ge, Y., Hadaway, A., & Marriott, D. (2011). Energy consumption and conservation in food retail. *Applied Thermal Energy, 13*, 147–156.
Timma, L., Skudritis, R., & Blumberga, D. (2016). Benchmarking analysis of energy consumption in supermarkets. *Energy Procedia, 95*, 435–438.
Van den Broek, K., & Walker, I. (2019). Exploring the perceptions of drivers of energy behaviour. *Energy Policy, 129*, 1297–1305.
Waeraas, A. and Nielsen, J. A., (2015). Translation theory 'translated': Three perspectives on translation in organizational research. Working paper No. 16. Norwegian University of Life Science. https://www.nmbu.no/sites/default/files/pdfattachments/hh_wp_16_2015.pdf
Wilhite, H., Horta, A., Schmidt, L., & Bartiaux, F. (2014). Socio-technical and cultural approaches to energy consumption: An introduction. *Nature and Culture, 9*(2), 115–121.
Winner, L. (1977). *Autonomous technology: Technics-out-of-control as a theme in political thought*. MIT Press.
Wong, C. M. L. (2016). Assembling interdisciplinary energy research through an actor network theory (ANT) frame. *Energy Research and Social Science, 12*, 106–110.
Woods, R., Skeie, K. S., & Haase, M. (2017). The influence of user behaviour on energy use in European shopping centres. *Sustainable Development, 25*(*1*), 11–24.
Woolgar, S. (1991). The turn to technology in social studies of science. *Science, Technology & Human Values, 16*(*1*), 20–50.
Zaatari, M., Novoselac, A., & Siegel, J. (2016). Impact of ventilation and filtration strategies on energy consumption and exposures in retail stores. *Building and Environment, 100*, 186–196.
Zibarras, L. D., & Coan, P. (2015). HRM practices used to promote pro-environmental behavior: A UK survey. *The International Journal of Human Resource Management, 26*(*16*), 2121–2142.