# *Enhancing customer participation in smart energy systems through behavioral science and economics*

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# Abstract (English)


This doctoral dissertation is inspired by the need to explore the human dimension of the clean energy transition for climate change mitigation and adaptation, through the application of behavioural science and economics principles.

The first chapter systematically reviews behavioural intervention studies that targeted encouraging of energy conservation and adoption of energy efficiency measures. A total of 56 studies, primarily from the fields of behavioural and social sciences, were evaluated for the effectiveness of behavioural interventions to produce long-term changes to energy consuming behaviour. The aim is to identify the behavioural biases that were overcome, the contexts in which particular types of interventions are more successful and to arrive at reliable long-term energy savings that could be achieved when implemented at scale.

The second chapter looks into behavioural traits, in particular the procrastination trait, of residential consumers and assesses their impact on the success of policy interventions. Behavioural experiments, in the form of online surveys were conducted on residents in Singapore to test if their decision to postpone replacement of inefficient electric appliances was due to severe procrastination traits. Further, with statistical analysis, we investigated the prominent contextual factors that could influence the appliance upgrade decision. Results from the behavioural experiment suggest that irrational procrastination could be corrected by behavioural interventions that frame the distant benefits of positive action and the loss due to inaction in the present time context. The role of behavioural interventions for correcting the discounting of future climate mitigation actions is explored further.

The third chapter of the thesis delves into behaviour change in the society and how persistent behavioural changes could be brought about through the simultaneous engagement of multiple players in a sector. The application of Information & Communication Technologies along with behaviour change interventions are explored for a systemic transformation. Using stakeholder discussions with the multiple players involved in the building sector in India, a strategy document is proposed to bring about an increased awareness and faster adoption of resource-efficient homes and buildings. This thesis further translates all the results into policy recommendations for the application of behavioural economics into effective energy policy.

# Table of Contents

# List of Figures

## List of Tables

# Chapter 1: Introduction

As the world gets dangerously close to alarming levels of carbon emissions in the atmosphere, policy makers across the globe are frantically weighing all possible options to find alternative energy sources while simultanelusly squeezing every joule of energy from available fossil fuel resources. With the current rate of population growth and ever-increasing consumption of energy, it looks more and more likely that we are bound for a future with dangerously high carbon emissions and very high energy prices – unless we reverse this pathological energy consumption behavior.

Most people, including the least educated, are already aware of this problem with varying levels of accuracy. But very few have yet adopted methods to beat this problem by altering their ways of energy consumption. After all, how many of us would like to make sacrifices to our comfortable lifestyles for a far distant future. It is not that people do not know what needs to be done, they are not motivated enough to change their behavior. Humans are seldom known to behave rationally, and energy consumption behavior is a very good example.

Solving this peculiar problem would require going to the basics and asking some fundamental questions: What motivates humans to change their behavior? Understanding this and engaging with individuals, households, communities and business sectors with effective behavioural interventions is an urgent, critical step towards low carbon development. Communicating the results of these interventions to policy makers could aid them in framing policies that are efficient as well as consumer-friendly. Making difficult but sensible changes to our energy consumption behavior today will lead to a better future with stable emissions concentrations and predictable energy prices. Therefore, the path to a sustainable low-cabon development is by motivating the energy consumers' behavior, one person, one household and one sector at a time until the whole world gains momentum towards a sustainable energy future .

**The human dimension of energy transition:**

The transition of energy systems towards sustainability requires the acceptability of the changes that accompany the transition. This is extremely challenging due to the fact that most consumers do not intrinsically relate their daily behaviours such as watching TV, storing food in the fridge or doing laundry with electricity consumption. The invisibility of electricity during its consumption makes it even more difficult for them to link their behaviours with carbon emissions and environmental degradation.

Pricing electricity by including environmental externalities is one possible way to highlight the environmental cost of energy consumption. However, price changes can hurt the poor low consumers more than the richer and more extravagant consumers, and is therefore used sparingly in policy. Creating awareness among the consumers is more popular policy measure. Providing feedback with smart devices is a more recent phenomenon that has shown promise in recent years. However, critics argue that the extra information may get “backgrounded” once the novelty of the device wears off. Moreoever, there is an added cost involved in seeking consumer attention and it may not always the most economical option.

It is therefore a necessity to think beyond technological and tariff measures and motivate the consumers towards clean energy transition. Behavioural economics fulfills this need by applying theories of psychology and economics to enable behaviour change in energy consumers. As opposed to classical microeconomics that relies on theoretical approaches and demand-supply equations, behavioural economics relies more on empirical studies and is now treated as an effective complement to microeconomics. This thesis explores the application of behavioural science and economics to invoke consumer participation towards a rapid transition towards a low carbon energy system.

**Roadmap of the thesis:**

This thesis is organized as defined in the figure below.  Chapter 2 presents a systematic review of the 56 studies on the application of behavioural interventions in the energy sector, focussing on residential consumers. Highlighting the fact that consumers are “predictably irrational”, it goes on to list the most important behavioural biases and the ways to target those biases.

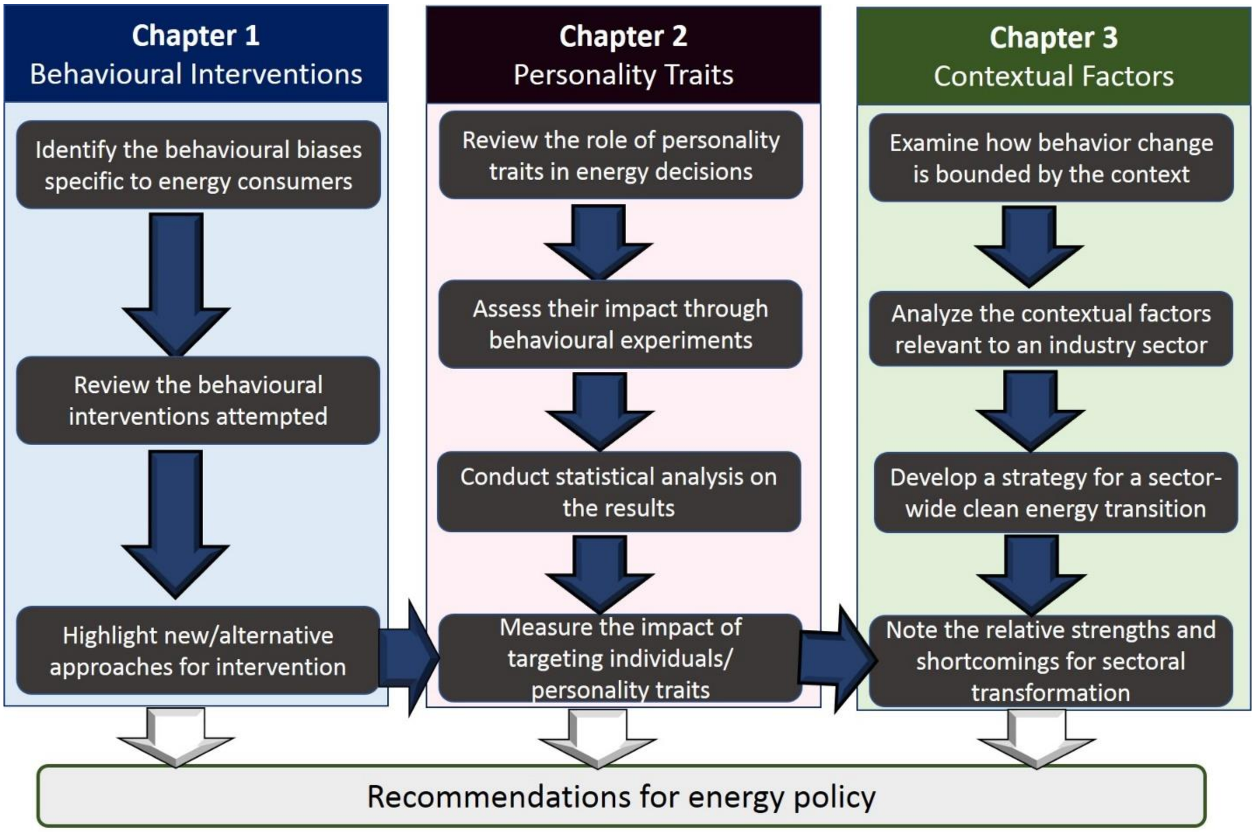


Figure 1: Roadmap of the thesis

Next, varied case studies, spread over a large time horizon and multiple geographies are reviewed. The review raises important questions on previous behavioural intervention studies and analyzes their effectiveness and the durability of observed behaviour changes. Salient successes and failures in the approaches used in the studies are discussed. Prominent types of behavioural interventions are discussed in the context of energy policy. Finally the chapter concludes with policy recommendations for a more systematic inclusion of behavioural interventions in energy policy.

Even the noblest of proenvironmental intentions if delayed inadvertently can lead to severe environmental degradation and irreparable losses. The cost of inaction or delayed action, particularly in the context of a changing climate can be alarmingly high. Irrational procrastination of proenvironmental actions, by individuals and institutions alike, can close the tiny window of opportunity we now have to avoid exceeding the temperatures that could cause severe damages to the climate. Chapter 3 starts with the limitations of energy policy that treats all consumers equally. This chapter expresses the need to acknowledge differences in individual capability for changing energy consuming behaviour. The chapter discusses why procrastination — a recently rising malady, when not addressed sufficiently can grow into a menace for sustainable development. This chapter attempts to measure procrastination in the context of upgrading to efficient appliances in households. A randomized control trial experiment is conducted in Singapore, where highlighting the cost of inaction is tried as a method to address procrastination. The results are analyzed to find the role of procrastination trait in energy efficiency purchases. The role of behavioural traits and contextual factors in the delay in energy efficiency upgrades is discussed. Equipped with ample statistical proof, suggestions are given to energy labelling standards by including concerns for consumers' personality traits and making provisions for irrational future discounting in a few consumers.

Unlike the classical microeconomic model which assumes rational behaviour irrespective of the context, behavioural economics recognizes the context-dependency of human behaviour. Unfortunatey, energy policies until now fail to factor in the contextual factors in energy conservation and energy efficiency. Any generalizations on possible behaviour changes is therefore meaningless unless the conextual factors are discussed and controlled. The quantum of behavour change too is often bounded by the societal or sectoral norms in which the individual operates. Chapter 4 addresses this crucial limitation in energy policy and aims to define a multi-stakeholder approach to simultaneously influence an entire sector towards positive behaviour change. The possible ways in addressing a sectoral behavioural change towards decarbonizing the building sector is discussed in the specific context of India, a rapidly developing country. The relative merits of such a sector-wide strategy vis-a-vis an individual-focussed approach is discussed.

The thesis concludes with recommendations on the type of behavioural interventions to be included in energy policy and the type of individuals and groups each type of interventions should target. The need for the government to play a more active role in invoking behaviour change is discussed while highlighting high-priority areas for intervention.

# Chapter 2: A systematic review of behavioural interventions for energy consumers


## Chapter Abstract

This chapter systematically reviews behavioural intervention studies that targeted encouraging of energy conservation and adoption of energy efficiency measures. A total of 56 studies, primarily from the fields of behavioural and social sciences, were evaluated for the effectiveness of behavioural interventions to produce long-term changes to energy consuming behaviour. The aim is to identify the behavioural biases that were overcome, the contexts in which particular types of interventions are more successful and to arrive at reliable long-term energy savings that could be achieved when implemented at scale. Although most of these studies originated from the US and Europe, the relevance of our findings are equally applicable to the rest of the world. The application to diverse target groups and the results obtained were analyzed. Studies that applied behavioural economics principles to the energy-poor and their relevance particularly in developing countries were also discussed. We propose policy recommendations to electricity utilities that are considering the large scale application of behavioural interventions.

## 2.1 Introduction

Human consumption of energy resources is a critical contributor to climate change. Therefore, changing human behaviour towards higher efficiency and more sustainable consumption patterns is crucial in addressing climate change and environmental degradation (IPCC, 2015). The IEA defines energy behaviour as all human actions that affect the way that fuels are used to achieve desired services and accordingly, behaviour change as any changes in these actions. Behaviours considered relevant to individual or household energy consumption include household energy consumption, energy curtailment, energy efficiency investments and pro-environmental behaviours such as purchase of green energy. Energy efficiency has come to play a central role in energy policies and is now considered the “first fuel” for an affordable, realistic energy development strategy (IEA, 2016).

### 2.1.1 Energy-Efficiency Gap and Behavioural Economics

One of the oft-cited reasons for the failure of energy-efficiency uptake is that energy policies based on neo-classical economics make strong assumptions that individuals can access information freely and completely and can behave rationally to maximize their utility. However, in reality, individuals are proven to be “predictably irrational” (Ariely, 2008) in making decisions concerning their daily life. In most aspects of decision-making, and particularly in complex decisions such as energy efficiency, people rarely consider all the costs and benefits involved and often indulge in immediate gratification at the expense of their own long-term interests. This “energy efficiency gap” (Allcott & Greenstone, 2012) or “energy paradox” (Jaffe & Stavins, 1994) often leads to a wide disparity between the observed level of energy efficiency investments and what is considered economically optimal.

Behavioural economics has challenged the assumptions in traditional economics and has proven that aside from the two traditional variables—price and income, human decisions can be affected by a host of different ways (DellaVigna, 2009; Kahneman & Tversky, 1979; Thaler & Sunstein, 2008), some of which could be explained with insights from psychology. Research in behavioural economics has successfully demonstrated that many “behavioural failures” in energy efficiency could be corrected using non-pecuniary interventions that target the irrational behaviour. Governments have started to increasingly recognize its role and importance in energy policy making in the past few years (DEFRA, 2010; Sussman & Chikumbo, 2016) . DellaVigna (2009) surveyed empirical evidence from a range of applications in the field and lists a comprehensive set of behavioural deviations from standard models, although only a few mechanisms can be applied to energy policy. A list of several behavioural economics principles have been suggested by Houde and Todd (2010) with practical implications for energy use. Numerous studies have been conducted in the past few decades, both in the laboratory and in the field, to establish causal links between macro-level factors, personal factors and human behaviour. A systematic review of these studies and experiments can shed light on the most powerful biases that affect energy efficiency investment behaviour and the most cost-effective ways to tackle them.

### 2.1.2 Previous studies on behavioural interventions in energy sector

Some of the earliest reviews on human behaviour and residential electricity consumption were conducted by social psychologists who reviewed simple attitudinal surveys on small groups of households (Brown & Macey, 1983; Seligman, Darley, & Becker, 1978) Findings from these clearly demonstrated a link between electricity consumption and energy-related attitudes and beliefs. However, they could not elicit how these attitudes could be converted into affirmative actions. Most of the studies reviewed by them were information seeking surveys, utility pilot projects or one-off energy audits that could not measure the impact of interventions in the longer term. Moreover, studies on voluntary energy conservation programs often suffered from self-selection bias and could not correctly estimate the program-induced energy savings (Hartman, 1988).

Later reviews started focusing on the effects of specific types of behavioural interventions. Farhar and Fitzpatrick (1989) reviewed 17 studies assessing the effect of information feedback and reported reduction in consumption in the range of 5% to 20%.Fischer (2008) reviewed 26 projects from ten developed countries that clearly demonstrated that feedback stimulates electricity savings, ranging from 1.1% to over 20%. However, she also notes that in a few instances, that no savings were found. Similarly, based on 36 studies implemented between 1995-2010, Ehrhardt-Martinez et al. (2010)estimate that a range of feedback mechanisms —

from enhanced billing to appliance level feedback — can potentially reduce 4% to 12% of household electricity consumption. Lokhorst et al. (2011) analyzed 19 studies containing commitment making and conclude that commitment making does induce behaviour change but they fail to establish why and how commitment is effective. Most of the studies reviewed in the literature leave crucial questions concerning the conditions under which the interventions were most successful. Many of the studies were short-term, and involved relatively small groups of consumers. Only one type of intervention was analyzed by most studies, without delving into possible complimentary interventions. Also, the persistence of the energy savings after the removal of the interventions was not discussed by many.

Critical questions that still remain are:

- What were the prominent behavioural biases that were targeted with behavioural interventions?
- Why did the various studies with seemingly similar interventions have vastly differing outcomes?
- Does a larger and more heterogeneous sample lead to different results?
- Which type of interventions resulted in persistent energy savings?
- How much of the behaviour change can be imbibed into consumers' daily routines?
- What potential impact can the policy makers expect from large-scale adoption of behavioural interventions?

We build on existing reviews by including varied types of interventions, by including studies targeting diverse categories of people and by analysis using distinct parameters such as the duration of the interventions, sample sizes and the persistence of goals achieved. We aim to answer the questions previously raised, by slicing and dicing the case studies on six criteria and analyzing the results obtained.

### 2.1.3 Selection Procedure

The main sources of information were digital online databases, including SCOPUS, Web of Science, Google Scholar and National University of Singapore Library Catalogue providing access to ABI/Inform, JSTOR, PsycINFO, ScienceDirect and several other databases. A preliminary keyword search on behavioural interventions for energy conservation and energy efficiency initially resulted in numerous studies from diverse fields such as Psychology, Economics, Energy Policy, Buildings, Environment and Consumer Research. Further, reference lists of articles were used to identify additional literature sources. These were then filtered based on presence of an experimental design, specific energy behaviours targeted, quantifiable impact of the intervention in terms of energy or resource savings and statistical analysis of the results obtained. Studies that followed up and tested the applicability and durability of a related study were included to compare more recent results with the previous ones.

This search finally resulted in 47 peer-reviewed journal articles, 6 working papers and 3 papers from conference proceedings. Publication dates of these studies ranged from 1976 to as recent as 2017. Although a majority of these studies originated from the US and Europe, the relevance of our findings is equally applicable to most of the world. **Error! Reference source not found.** Appendix A gives the complete list of the studies reviewed, their stated objectives, the interventions used and the impacts of the interventions. This selection of studies is by no means exhaustive; nevertheless, it does provide an overview on the various types of behavioural interventions that were tested for energy efficiency and conservation.

The case studies identified were evaluated using the following six criteria:

- Experiment Design
- Behavioural Economics principles
- Duration of study
- Persistence of energy savings
- Number of participants
- Targeted groups

## 2.2 Review of case studies

### 2.2.1 Experiment Design

A wide spectrum of research designs were applied in behavioural interventions. Broadly, they could be categorized as either Qualitative approaches that try to provide meaningful insights into behavioural problems and offer actionable solutions or Quantitative approaches that take a formal process to test cause-and-effect relationships. Results from qualitative studies such as on how householders interact with feedback from smart energy monitors (Hargreaves, Nye, & Burgess, 2010, 2013) were useful to indicate of the complexity of real-life problems and to provide crucial information on how and why a particular intervention works. Focus groups where participants could explain what brings about the greatest change (Brandon & Lewis, 1999) are highly invaluable to draft policies for the larger populations. Quantitative studies, on the other hand, provide reliable data by objectively measuring the impact of behavioural interventions without delving into the causative links.

When participants could not be grouped randomly owing to field constraints (Gonzales, Aronson, & Costanzo, 1988), privacy constraints (Beatty, Blow, Crossley, & O'Dea, 2014) or operational constraints (Agarwal, Rengarajan, Sing, & Yang, 2017) ,quasi-experiments were conducted by a few studies. Although often deemed not good enough to determine the precise *causal* impact of an intervention in changing a particular behaviour, this design could sometimes be the only option to conduct interventions in the field. Randomized controlled trails (RCT), on the other hand, were more suited to draw causal inferences. These formed the bulk of the experiments—both in the laboratory setup and in the field. RCTs with participant groups representing a range of real-world characteristics such as age groups or housing tenures could possibly increase the breadth of applicability of the results. However, having too many conditions may lead to results with large standard deviations with reduced significance of differences between treatments (Brandon & Lewis, 1999). Instead, having lesser number of groups with a greater number of participants could produce better results.

Surprisingly, many of the RCT studies that were reviewed did not have a clearly defined control group. For instance, the studies that evaluated the use of social norms in Home Energy Reports

(HER) did not verify if the delivery of the HER (in addition to the existing utility statement) itself had led the consumers to believe that they were being watched, and therefore changed their behaviour. Having a control group that did not receive the HER would have helped to clearly distinguish between the impact of social norms and the impact of sending an extra report. A study on disaggregated feedback (Attari, Gowrisankaran, Simpson, & Marx, 2014) had participants both from the control and treatment groups living in the same building and frequently interacting about their new feedback devices. This could have led to spill-over effects, which resulted in high energy savings even in the control group. Studies that lasted for very short time periods didn't have clear baseline measurements. At least part of the high savings reported in such studies could be attributed to the Hawthorne effect (Tiefenbeck, 2016). On the other hand, studies with longer intervention periods produced slightly lower but more reliable results. Consent bias was evident in a few field experiments that were conducted on more educated consumers with professedly pro-environmental attitudes. Many RCT studies that examined the impact of social norms and feedback could not clearly differentiate between the impacts caused by the feedback and by the norms. The impact of the weather and seasonal factors during the intervention period received scant attention in several studies. Although a vast literature suggests that household and demographic characteristics play a major role in the baseline consumption and the potential savings from interventions, very few studies tried to examine the influence of such contextual variables that could have impacted the effectiveness of the behavioural interventions.

10 of the 56 studies reviewed had considered a longitudinal design that monitored the intervention long enough to verify if changes in energy consumption were due to the intervention alone and not due to extraneous factors. And two of these ran for only a few weeks, where the Hawthorne effect could not have been eliminated, i.e. participants could have changed their behaviour for a short time because they were made aware of being part of an experimental study. Only one of the studies was a cohort study that analyzed field data of adopters of an energy conservation program and compared them to non-adopters. Given the obvious preference for a quantitative analysis, particularly with RCTs, it could be said that most studies tended to be scientifically rigid and evidence seeking in their approach. However, given the fact that much

more needs to be understood in consumption behaviour patterns, having a lesser focus on rigid experiment designs and having an equal emphasis on consumers' qualitative feedback, could possibly derive more information and increase the scope of future interventions. More observational and longitudinal studies could also help decipher the contextual factors in the energy consumers' decision making.

### 2.2.2 Behavioural Economics principles

A wide range of behavioural interventions based on BE principles have been utilized in various studies. In a recent review of insights for environmental policies, the OECD (2017) developed a typology of behaviour interventions with seven broad categories. We build on this topology and define intervention categories based on the underlying principles and the biases that they target to overcome. Table 1 lists some of the important biases observed in domestic energy consumption behaviours and possible ways to treat them with behavioural interventions. Although the OECD's review covered several pro-environmental behaviours concerning energy, transport, water, food and waste management, this study focuses only on interventions specific to direct or indirect energy use. Table 2 below lists the types of interventions identified in the studies reviewed. Several combinations of these categories of interventions have also been utilized, catering to various objectives of the experiments.

Table 1: Behavioural biases in energy consumption and possible treatments

| Biases | Description | Possible Treatments |
|---|---|---|
| **Information gap** | Consumers cannot easily access all the relevant information to engage in energy saving behaviours | Provide relevant information, using various channels to raise awareness and to enable an informed decision |
| **Bounded Rationality** | Consumers have limited capacity to process complex information. When faced with complex choices or too much information, consumers use their own ways of simplifying the choices by resorting to "rules of thumb" | Simplify the choices and frame complex information in simpler and user-friendly ways |
| **Time inconsistency** | Consumers prefer instant gratification and choose smaller short-term benefits over larger longer term benefits | Repackage costs such that benefit is gained upfront. Set goals and employ commit mechanisms to achieve higher long term benefits |
| **Salience bias** | Consumers' decision is swayed by vivid and salient information rather than by statistically correct information | Make key energy information salient by providing real-time feedback and state energy-saving advice with salient examples, to better retain it. |
| **Status quo bias** | Consumers tend to not change their habits and prefer to stick with defaults, unless they face a strong reason to modify their behaviour | Set optimal default options such as default settings for appliances or automatic enrolment in energy efficiency programs. |
| **Reference dependence** | Consumer compare alternative energy purchases against a reference option | Frame energy information relative to an effective reference point. |
| **Mental accounting** | Consumers often have separate mental accounts for one-off high value purchases and multiple low value savings. | Frame energy savings in ways to overcome mental accounts. |
| **Loss aversion** | Consumers focus on losses much more than on gains | Frame energy information as preventing a loss, rather than incurring a gain |
| **Bounded self interest** | Individuals are motivated not only by maximizing their own utility, but are also motivated by altruism, preservation of public good and fairness. | Leverage this by the use of social norms, e.g. by providing information about what others are doing, or by presenting conservation as a public good |

## Table 2: Intervention types identified in the studies

| Studies | Information Provision | Feedback | Financial Incentives | Message Framing | Choice architecture | Social Norms | Commitment & Goal-setting |
|---|---|---|---|---|---|---|---|
| Abrahamse et al. (2007) | ■ | ■ | | | | | ■ |
| Agarwal (2017) | ■ | ■ | | | | | ■ |
| Agha-Hossein et al. | ■ | ■ | | | | | |
| Allcott & Rogers (2014) | ■ | ■ | | | | ■ | |
| Allcott & Taubinsky | ■ | | ■ | | | | |
| Allcott (2011) | ■ | ■ | | | | ■ | |
| Anderson & Claxton | ■ | | | | | | |
| Asensio & Delmas (2014 | | | | ■ | | | |
| Asensio & Delmas (2015) | | | | | | | |
| Attari et al. (2014) | ■ | ■ | | | | | |
| Ayres et al. (2009) | ■ | ■ | | | | ■ | |
| Baca-Motes et al. (2013) | ■ | | | | | | ■ |
| Bager & Mundaca (2015) | ■ | ■ | | ■ | | | |
| Battalio et al. (1979) | ■ | ■ | ■ | | | | |
| Beatty et al. (2014) | | | | ■ | | | |
| Becker (1978) | ■ | ■ | | | | | ■ |
| Benders et al. (2005) | ■ | ■ | | | | | |
| Brandon & Lewis (1999) | ■ | ■ | | | | | |
| Costa & Kahn (2013) | ■ | ■ | | | | ■ | |
| Dinner et al. (2011) | ■ | | | | ■ | | |
| Dolan & Metclafe (2015) | ■ | ■ | ■ | | | ■ | |
| Ferraro & Price (2011) | ■ | | | | | ■ | |
| Gans et al. (2013) | ■ | ■ | | | | | |
| Gonzales et al. (1988) | ■ | | | ■ | | | ■ |
| Green & Peloza (2014) | | | | ■ | | | ■ |
| Harding & Hsiaw (2014) | ■ | ■ | ■ | | | | ■ |
| Hargreaves et al. (2010) | ■ | ■ | | | | | |
| Hargreaves et al. (2013) | ■ | ■ | | ■ | | | |
| Harries et al. (2013) | | ■ | | | | ■ | |
| Houde et al. (2013) | ■ | ■ | | | | | |
| Jessoe & Rapson (2014) | ■ | ■ | | | | | |
| Kallbekken et al. (2013) | ■ | | | | | | |
| Katzev & Johnson (1983) | ■ | ■ | ■ | | | | ■ |
| Khashe et al. (2016) | | | | ■ | | ■ | |
| Kraus (2014) | | | | | | | |
| Liu et al. (2016) | ■ | | | ■ | | ■ | |
| McCalley & Midden | ■ | ■ | | | | | ■ |
| McCalley & Midden | ■ | | | | | | ■ |
| Miller (2013) | ■ | | | | | ■ | ■ |
| Never, (2014) | ■ | | ■ | ■ | | ■ | |
| Nicole et al (2016) | ■ | ■ | ■ | | | ■ | |
| Nicolson et al. (2017) | | | | ■ | | | |
| Nolan et al. (2008) | ■ | ■ | | ■ | | ■ | |
| Pallak & Cummings | ■ | ■ | | | | | ■ |
| Pellerano et al. (2016) | | | ■ | | | ■ | |
| Schleich et al. (2013) | ■ | ■ | | | | | |
| Schultz et al. (2007) | ■ | ■ | | | | ■ | |
| Schultz et al. (2015) | ■ | ■ | | | | ■ | |
| Schwartz (2015) | | | | ■ | | | |
| Seligman et al. (1978) | ■ | ■ | | | | | ■ |
| Shippee & Gregory | ■ | ■ | | | | | ■ |
| Slavin et al. (1981) | ■ | ■ | | | | | ■ |
| Staats et al. (2004) | ■ | ■ | | | | | |
| Tiefenbeck et al. (2016) | ■ | ■ | | | | | |
| Van de Velde et al. | | | | ■ | | | |
| van Houwelingen & van | ■ | ■ | | | | | ■ |
| Wilhite & Ling (1995) | ■ | ■ | | | | | |
| Xu et al. (2015) | | | | ■ | | | |
| Frequency | 46 | 36 | 8 | 14 | 1 | 16 | 16 |

### 2.2.3 Information provision and Feedback mechanisms

Energy being an invisible good, consumers often cannot inter-relate their daily behaviour with energy consumption. Lack of information is hence among the most common reasons why consumers under-invest on energy efficiency. Strategies to provide information can either be Antecedent— prior to the performance of target behaviour or Consequent— after the behaviour. Examples for antecedent information include prompts, energy saving tips, energy labels, pricing information and individualized energy audits. Examples for consequent information include feedback provided through energy bills, home energy reports, smart energy meters and in-home display devices.

In one the earliest framed field experiments on electricity consumption, Battalio et al.(1979) evaluated consumers' response to information such as household energy conservation tips and instructions on how to compute their electric bill. As opposed to other treatment groups that received rebate payments or feedback, the group of consumers that received additional information alone had surprisingly increased their consumption. A plausible explanation for this was that with information provision, consumers who had initially over-estimated energy costs might have revised their estimated costs in a downward direction, thereby resulting in increased consumption. Similar results were obtained by Kallbekken et al. (2013) while evaluating the effect of energy labels on appliance purchases using a natural field experiment. They found that labeling of household appliances on its own was not enough and that combining it with training of sales staff induced more consumers to buy energy-efficient appliances. In a similar natural field experiment, limited impact of energy information was observed by Anderson and Claxton (1982) on the purchase of frost-free refrigerators, although a more encouraging impact was observed in the lower priced, small-size market segment, with 14% energy savings. Through a series of laboratory and field experiments, Allcott and Taubinsky (2015) observed that despite being strongly informed about the financial benefits of CFL bulbs, most consumers still preferred incandescent bulbs and that the willingness to pay for a CFL was only marginally higher than a regular one. Customers served by trained home energy auditors are usually more informed and were observed by Gonzales et al. (1988) to be more likely to apply for energy retrofit programs. However, a longitudinal measure showed no difference in energy consumption in their study. All this evidence suggests that although providing additional information can increase consumers' awareness, it does not always result in declined energy consumption. The socio-economic factors, contextual variables and the target groups for which information provision is found to be most effective need to be evaluated to derive any meaningful conclusions.

While information provision on its own seems to have limited impact on real energy savings, an increasing number of studies have suggested that providing feedback on the actual consumption often results in decreased energy use. Feedback helps the consumers learn about the exact consequences of specific behaviours, which in turn results in reduced uncertainty in decision making. Energy actions that are consciously performed in the presence of regular feedback eventually results in habit formation, which ultimately leads to internalization of the behaviours. Three types of feedback programs can be observed from the reviewed studies.

*Indirect feedback:*

Most of the earlier studies focused on indirect feedback that has been considerably delayed before reaching the energy user, normally via enhanced or informative billing. Studies on informative billing by Wilhite and Ling (1995) in Norway based on meter readings at 60-day intervals (rather than at yearly intervals) showed a 10% reduction in consumption compared to the control. Persistence of these savings over a three-year investigation period strongly suggests that a more informative bill leads to persistent energy savings. Moreover, consumer response after the feedback showed that enhanced billing often led to a more energy-conscious consumer, with positive attitudes towards the electric utility. Another field trial on over 1500 households in Austria (Schleich, Klobasa, Gölz, & Brunner, 2013) too showed that significant savings (4.5%), but were concentrated among households lying in the 30th-70th percentile of consumption. Feedback provided either by post or via a web portal was found to be equally effective. However, another field experiment that simultaneously compares seven feedback conditions resulted in average savings of only 0.39% to 4.84% (Brandon & Lewis, 1999). Three of the conditions tested resulted in an overall increase in consumption. The lower quantum of observed savings is consistent with findings from a review by Davis (2011) who reported between 0.9% to 2.9% and by Costa and Kahn (2013) who reported between 1.1% to 3.6% reductions with an average of 2% across all households, in response to detailed Home Energy Reports. Davis notes that possible factors that could have influenced the treatment effects include baseline usage, size of the house, number of occupants and the age of head of household. Ayres et al. (2009) tested for the influence of report templates and their envelope sizes and observed that reports using a graphic template and sent in a standard sized business envelope (similar to the one used by the utility) were more effective than the ones sent in a narrative template or in a non-standard sized envelope. This suggests that the effectiveness of indirect feedback may be influenced by several contextual variables such as the duration of feedback, its frequency and the presentation format. Political ideology too appears to be a factor, with Costa and Kahn (2013) finding that liberals and environmentalists are more responsive to home energy reports than conservatives.

*Real-time feedback:*

Many of the recent studies reviewed have used several technological means such as Advanced Metering Devices, In-Home-Displays, Smart phones, Web applications and other devices to convey instantaneous feedback to the consumers. This overcomes the inherent delay present in indirect feedback by instantaneously informing the consumers about the consequences of energy use. Advanced metering devices (smart meters) and In-home displays are the most frequently devices for real-time (or near real-time feedback), with realized savings in the range of 6.4% to 13%.Combining real-time feedback with other measures such as providing personalized information (Benders, Kok, Moll, Wiersma, & Noorman, 2006), information framing (Bager & Mundaca, 2015) or pre-payment mechanisms (Gans, Alberini, & Longo, 2013) produced much larger savings between 8% to 18%. Interestingly, real-time feedback provided for water consumption also resulted in 22% lesser consumption, leading to indirect energy savings (Tiefenbeck et al., 2016).

A wide variation in the treatment effects is observed across the studies, which could be attributed to the variations in end uses, seasonal factors and home ownership. It should be noted that high savings achieved in controlled trials might not always be replicated in actual field conditions. Studies suggest that the effectiveness of smart meters may be moderated by the household, social or political contexts (Hargreaves et al., 2013) and ensuring supportive environments is therefore crucial for the success of real-time feedback measures, at least in the initial stages. Evaluation of the success of feedback over the longer term exposes that the high reductions that were initially achieved are likely to decline with time, and the new information will eventually get "backgrounded" (Hargreaves et al., 2013). Accordingly, energy policies based on the savings potential shown by the feedback experiments must scale down their expectations to avoid frustration.

The consumer response was found vary considerably depending on the salience of the information presented. Feedback that highlighted the aggregate figures such as monthly consumption was found to be more effective than the smaller daily or hourly values (Bager & Mundaca, 2015; Schultz, Estrada, Schmitt, Sokoloski, & Silva-Send, 2015). Feedback that direct consumers' attention to specific conservation actions, (like switching off an air conditioner) was found to be more effective than generic feedback on total consumption(Seligman et al., 1978). Increasing the interactivity of the feedback could likely engage the consumers towards better results. For example, evidence from a study on building occupant behaviour (Agha-Hossein et al., 2015) suggests that simple and effective real-time feedback, in combination with interactive posters and prompts can encourage participation and promote energy savings. The study however, does not reveal what needs to be done after the initial curiosity tapers off.

*Disaggregated feedback:*

Recent advances in technology have made it possible for energy monitoring systems that breakdown electricity consumption into end-use categories or appliances (e.g. refrigerator, TV, water heater, AC, washing machine). Such disaggregated information can accurately inform the consumer about the key areas of energy consumption and thereby enable to take appropriate conservation or efficiency measures. A field experiment on 101 apartment units fitted with plug-level "modlets" reports 12-23% reduction in electricity use, concentrated among those reporting a higher willingness-to-pay for such energy monitoring devices (Attari et al., 2014). Although at least a part of the extraordinarily high savings reported in this study could be attributed to contextual factors (as discussed later), their results do corroborate the view that considerable efficiency losses can be avoided by providing detailed, appliance-level information. Therefore, providing relevant information and enhanced feedback must be considered as the foremost step in energy efficiency policies.

Evidence from the feedback studies suggests that the most productive type of feedback is the one that is the most instantaneous, frequent, tailored, interactive, disaggregated and salient. Feedback that clearly identifies the specific appliances and activities that consume the most electricity can apprise the consumer to take corrective actions. For information and feedback strategies to be most effective, it is not sufficient to merely provide accurate or detailed information. Rather, it is how the feedback is presented, that decides if the consumers are informed, engaged and willing to change their consumption behaviours. So it is imperative that all new measures and policies to roll out “smart” devices in consumer premises must first ensure that the feedback provided is relevant, useful, intelligible and easy to interpret, to gain the consumers’ trust and involvement.

### 2.2.4 Financial incentives

Rewards and financial incentives such a tax rebates, subsidies and loans for investments in energy efficiency are very common and perhaps the most expensive policy measures pursued by governments and utilities (Stern et al., 1986). There is a growing body of work in behavioural economics suggesting that combining financial incentives with other interventions can sometimes have synergetic effects, which could be larger than the sum of each intervention acting on its own (Stern, 1999). In the literature reviewed, financial incentives have been evaluated in combination with social norms (Dolan & Metcalfe, 2015), information provision and feedback (Battalio et al., 1979; Jessoe & Rapson, 2014; Slavin, Wodarski, & Blackburn, 1981), environmental framing(Schwartz, Bruine de Bruin, Fischhoff, & Lave, 2015) and goal setting (Katzev & Johnson, 1983; Slavin et al., 1981).

Evidence from a natural field experiment from the UK (Dolan & Metcalfe, 2015) shows that financial rewards for targeted consumption reductions work very well, with a 8% reduction in energy consumption, over a four-month period. However, the study also notes that the strength of the financial incentive is reduced drastically when social norm activation is simultaneously provided. In a large field experiment on the interaction between price and normative appeals, Pellerano et al. (2016) found that adding financial incentives to normative messaging could actually backfire and crowd-out the outcome of normative appeals. Similar outcomes were observed by Schwartz et al. (2015) even in a simulated experiment on 1172 individuals, where emphasizing on extrinsic, monetary benefits reduced the participants' willingness to enroll in energy-saving programs.

The effectiveness of financial incentives seems to be contingent on several contextual factors. Literature has shown that even with large subsidies, consumers' interest could sometimes be tepid (Stern, 1999). Lower rebates could sometimes cause more reductions in electricity use than higher rebates for reduced consumption (Battalio et al., 1979). Their implementation among poorer households is often much lower than in the general population (Never, 2014; Stern et al., 1986) . All this indicate that the acceptance of pro-environmental behaviours depends not on the size of the incentive, but rather, on the type of incentive offered, on how it is communicated and the groups to which it is targeted. Studies also suggest that the impact of rebates on energy consumption is often temporary; consumption returns to the baseline levels once the rebates are removed (Katzev & Johnson, 1983) . The cost-effectiveness and durability of financial incentives must firstly be justified before being adopted by energy policies.

### 2.2.5 Message Framing

Energy consumers are often limited by their cognitive ability and are therefore influenced by many cognitive biases which prevent them from making rational decisions concerning their energy use. Literature shows that by designing messages that either remove or take advantage of these biases, it is possible to increase the uptake of energy efficiency. Several studies have tried to change the semantic construction, the message contexts and the time frames of messages to target consumer biases such as loss aversion, mental account, reference dependence, status quo bias, mental accounting and time inconsistency of decision making. The studies utilized a variety of message framing such as emphasizing economic gains or losses, changing the time frame of economic benefits, highlighting the environmental or health impacts of actions, by changing the defaults and by labeling of payments.

Framing effect, first illustrated in prospect theory (Kahneman & Tversky, 1979) explains why people are more sensitive to prospective losses than prospective gains. Studies utilizing this concept of loss aversion have shown that loss-framed messages have a greater impact on energy savings than gain-framed ones. For example, in a quasi-experiment on 408 consumers planning for energy retrofits, Gonzales et al. (1988) noted that consumers who received loss-framed messaging (as loss from inaction) from trained auditors were more likely to apply for financing, as compared to consumers who received gain-framed messages (as gains from action). The advent of smart metering devices has enabled the provision of near real-time feedback to the consumers. However, studies that provide information alone are often insufficient to overcome the behavioural biases. In a randomized control experiment on 16 households with access to near real-time feedback on daily and nightly consumption, Bager and Mundaca (2015) observed that the intervention group with loss-framed and salient messaging has twice as much reduction in energy use as the reference group. However, the small sample size and the short duration of the experiment prevent us from drawing a strong interpretation of the results.

While loss-framed messages have shown reasonable success in energy conservation, the same could not be said about willingness to participate in demand-response measures. A recent survey experiment by Nicolson et al. (2017) on 2020 representative British consumers, tried to evaluate the consumers' willingness to switch to smart time-of-use (sTOU) tariffs. Participants were subjected to four different treatment leaflets—two of which used financial gain-based and loss-based frames respectively, while the other two used environmental gain-based and loss-based frames respectively. Their loss aversion was then elicited using a standard set of financial decision problems. Finally, the participants' willingness to shift to sTOU tariffs was measured on a 7-point Likert scale. Results of the experiment showed that although a third of the bill paying consumers showed willingness to shift to sTOU tariffs, a whopping 96% of the bill payers were found to be loss-averse—caring about avoiding losses than making gains and therefore unlikely to make the actual shift. Results of regressions show that loss aversion had the largest negative impact on their willingness, while loss-framing—both financial and environmental had no significant impact on the loss aversion scores.

Non-price messaging providing environmental and health based framing have been found be more effective than pecuniary frames in the studies reviewed. In testing the persistence effects of two message frames, Asensio and Delmas (2014) find that a health-based frame which highlights the human health benefits on marginal energy use induced higher and more persistent energy savings than cost savings frame. However the high peak conservation potential initially displayed started attenuating drastically over a span of 8 months, resulting in 6% net energy savings. The traditional cost savings frame fared much worse, with no significant conservation behaviour after the first six weeks. A study on advertising energy saving programs (Schwartz et al., 2015) shows that the enrollment in energy saving programs too could be greatly influenced by framing the environmental benefits. Their results also highlight that combining with the monetary benefits could in fact have a detrimental role. They advocate that if intrinsic benefits are taken care of, the monetary benefits could go without a mention.

Literature on ‘mental accounting’ shows that consumers often have separate mental accounts for one-time bulk purchases, more frequent smaller purchases and energy savings. This seems to be much more pronounced among the poor having high liquidity constraints and therefore are more focused on immediate expenses than on energy efficiency and long term savings (Never, 2014). Studies show that by utilizing this and by framing information that captures these mental accounts, it could be possible to overcome barriers to energy efficiency. Evidence from a quasi-experiment in the UK over a span of 8 years (Beatty et al., 2014) shows that mere labeling of cash payments to the elderly as “Winter Fuel Payment” as opposed to regular cash transfer increased the likelihood of spending the money on fuel by almost 14 times. While the policy implications of this finding are enormous, there seems to be a relative paucity of empirical field experiments that tried to explore mental accounting in energy efficiency.

Although message framing has been fairly effective in bringing about behavioural change, its efficacy was found to be non-uniform on different subsets of people. The role of individual differences in responding to framing was explored by two studies. A randomized online survey by Van de Velde (2010) on a fairly representative 260 Belgians revealed that the choice of the frame was most important while addressing women, people younger than 35 or older than 55 years, the less educated and the less pro-environmental people. On the other hand, men, people aged between 35 and 54, and those with pro-environmental attitudes were less affected by framing. Exploring the role of individual differences in responses to temporal and benefit framing, Xu et al. (2015) conducted an online experiment on 461 US residents. Their results revealed environmental framing was more effective on among political liberals than among the conservatives. In terms of the time frame of expected benefits, short-term economic benefits stimulated the most positive attitudes and were most effective, particularly among participants with low with low consideration for future consequences. This suggests that for achieving maximum impact, the message frame must be carefully designed, and due consideration must be given to socio-demographic characteristics of the population. Where possible, each segment of the population could be provided with benefits or threats that bring about maximum change in that segment.

### 2.2.6 Choice architecture and changes to defaults

While message framing refers to how the relevant information is framed to persuade energy decisions, choice architecture refers to how the options available are arranged such that the most optimal option is selected. While traditional economics assume all individuals to be equally capable of making an optimal choice irrespective of order in which the options are presented, behavioural economists have proven that people are often “irrational” and get affected both by the order of choices and by the option chosen as the default. Thaler and Sunstein (2008), in their best-seller book, argue that when people do not choose what is in their long-term best interests, it is up to the policy makers to “nudge” them by modifying the choice architecture without forbidding any options or significantly changing their economic incentives. They termed this approach as “libertarian paternalism”.

The default effect was reproduced by Dinner et al. (2011) in a series of three experiments and the ability of ‘Query Theory’ to account for reference dependence was tested. All the three experiments had a hypothetical context in which the participant must choose between compact fluorescent light bulbs (CFL) and incandescent light bulbs while renovating their house. Half the participants in each experiment had the incandescent bulb as the default while the other half had a CFL as default. In Experiment 1, details about the options were listed concurrent to making the choice. In Experiment 2, the details were provided after the decision was made. The final experiment had a 2x2 design in the order of displaying the default and displaying the aspects about either of the choices. All the three experiments clearly demonstrated the role of reference dependence in the default effect phenomenon. Implied endorsement of the default choice and the effort involved in making a choice too had potential role for the default effect. The study postulates that the effort in choosing a choice could have a crucial role if the decision takes a lot of time or requires physical or cognitive effort. And if the options have social consequences, then implied endorsement could have a larger impact on default effect. With no extra cost whatsoever, nudging could possibly be the most cost-effective option for energy policy.

### 2.2.7 Use of social norms

One of the recently popular non-pecuniary approaches in influencing consumption behaviour is the social norms approach, based on normative social influence. Normative social influence states that humans, as social beings, tend to conform to the society's perception of what is "normal" behaviour. While information provision and feedback creates greater awareness among the consumers, the social norms approach asserts that providing them with information about the average consumption of their peer groups increases their inclination to "conform" and emulate the social norm. Studies employing the social norms approach showed that messaging about social norms make people perceive what the normal behaviour is and change their accordingly. Social norms used in the studies focused on either 'descriptive norms'— that state what most people actually do or on 'injunctive norms'— that state what they ought to do.

Perhaps one the largest programme that uses the social norms approach is run by Opower, which partners with electric utilities primarily in the US for demand reduction. Opower sends periodic Home Energy Reports to the consumers, providing information on the average consumption of their peer groups, in addition to feedback on their own consumption. The programme was based on earlier studies that explored the power of social norms were by Schultz et al. (2007) and Nolan et al. (2008). Using a field experiment on 287 households, Schultz et al. (2007) examined if providing a descriptive message about the average of neighborhood's consumption reduced a household's energy use. Their results showed that social norm messaging either increased the consumption by 8.6% (called boomerang effect) or reduced it by 5.7% depending on whether the household is already consuming at a low or high rate. However, an additional positive injunctive message (smiling face symbol, if consumption was below average) eliminated the undesirable boomerang effect. Another field experiment by Nolan et al. (2008) on 46 participants showed that the group subjected to descriptive norms produced the maximum reductions (10.1%) as compared four other types of messages. However, these reductions eroded to 7.2% within two months. This experiment proves that energy could be conserved despite the private nature of normative messaging. Surprisingly, when asked to rate the five messaging types, respondents rated social norms as the least motivating. This shows how under-detected social norms possible are, as compared to other messaging alternatives.

Follow on studies by Ayres et al. (2009) and Allcott (2011) explored the impact and cost-effectiveness of Opower's programmes and discussed about the durability of the intervention. Ayres et al.(2009) studied the effect of peer comparisons in two utilities over seven months and twelve months respectively on approximately 75,000 consumers grouped by sizes of the houses and their value. It was noted that in both the experiments, households with initially high energy use saved more after the intervention. Houses with lower valuation saved more than higher valued houses. The observed energy reductions were 1.2% and 2.1% respectively, which were sustained though out the period of study. A much longer study on Opower's programme by Allcott et al. (2011) over two years on 600,000 households revealed more information on the expected size of the energy reductions and their durability. Savings ranged between 1.4% and 3.3%, averaging about 2%. Households which were initially in the top 10% of consumption decreased usage by 6.3% while those in the bottom 10% decreased by only 0.3%, The study notes that the intervention produced savings equivalent to that of a 11% - 20% increase in short-run electricity prices, and therefore compares favorably to other energy conservation policy measures in its cost effectiveness.

A noticeable drawback of all the above four studies that evaluated social norms is that none of them had a control group that received only the individual consumption and not that of the peers. Hence, they fail to differentiate between the savings that can be attributed to feedback on one's own consumption and to that of the peer group. A more recent field experiment

(Harries, Rettie, Studley, Burchell, & Chambers, 2013) that addressed these drawbacks in the experiments of Schultz et al. (2007) and Nolan et al. (2008) and revealed only a marginal and statistically insignificant reduction in energy consumption for the social norms group as compared to the individual feedback group. Their findings suggest that social norms information helps more to engage the consumers with the feedback than to reduce the consumption significantly. The reductions could be moderated by many factors such as the previous levels of consumption, existing consumption patterns and the primary electric appliances being used. However, the efficacy of the social norms approach is by no means to be overlooked. Literature suggests that norm based messaging has been remarkable in increasing individual participation in switching off appliances such as computer monitors (Miller, 2013), for encouraging enrollment in collective energy conservation measures (Liu, Veríssimo, & Farhidi, 2016) and in reducing indirect energy use by reducing water consumption (Ferraro & Price, 2011). Social influencing has also been found to be phenomenal in influencing peer's energy conservation behaviour (Khashe, Heydarian, Becerik-Gerber, & Wood, 2016) and in energy saving games and competitions (Kraus, 2014; Nicole, Ellen, Agassi, & Michael, 2016) the social norm is highlighted that others too are actively trying to their reduce energy use. All these indicate that employing social norms approach seem to be more successful in contexts where specific consumption practices are being targeted.

### 2.2.8 Commitment and Goal setting

Several studies have tried to explore the impact of setting of pro-environmental goals and consumers' commitment (both in public and in private) for energy conservation. Although such interventions have been proven to be effective, the exact causes that led to behavioural changes could not to be ascertained in many studies. When individuals are hindered with barriers such as procrastination, commitment mechanisms and goal setting are useful in defining a tangible objective, motivate them to achieve it and provide them a sense of fulfilment.

In a landmark study on the role of public commitment making to promote pro-environmental behaviours, Pallak and Cummings (1976) examined if the option of being publicly identified while making a commitment affects the quantity of energy savings. They conducted two separate experiments on consumers of natural gas and air conditioning in Iowa City, USA. In both cases, homeowners who made public commitments had a lower increase in consumption, relative to the private commitment groups and the control groups. The effect persisted for six months after the intervention. The results could not be attributed to conformance effect, since only details of participation were only “promised” to be made public; reduced consumption too was not publicized. This suggests that when individuals voluntarily commit in public, they subject themselves to more self-scrutiny, thereby leading to persistent energy conserving behaviours. Building on the findings of this study, Shippee and Gregory (1982) designed another field experiment that evaluated “mild” and “strong” forms of public commitment. However, contrary to the previous experiment that was conducted on residential consumers, this one was on 16 small commercial and industrial firms. The experiment’s design involved publicizing to the community about the commitments made by the “strong commitment” group and the savings achieved. In the case of “mild commitment” condition, only the participation was publicly acknowledged. Results show that as compared to the “no-advertisement” control group, the “mild” commitment group consumed 45% lesser natural gas, and the “strong” commitment group consumed 14% less. This shows that while a milder form of public commitment leads to positive attempts to remain committed, stronger conditions often leads to heightened public accountability and instills a fear of possible negative consequences. This could frustrate and dissuade the consumers, if they see that commitments could not be realized. This study therefore prescribes a simple public acknowledgement of energy conservation efforts, as opposed to audacious publicity for energy conserving firms.

Public commitments could affect how people exhibit their intentions for pro-environmental actions such as purchasing electric cars or solar panels; however these attitudes could vary strongly from their actual behaviour which often occurs away from public scrutiny. Evidence from a laboratory experiment on advertising appeals for environmentally friendly products (Green & Peloza, 2014) suggests that consumers are responsive to “other-benefit” appeals in contexts with increased public scrutiny but actually favor “self-benefit appeals” in a private setting. However, public commitment was found as effective as social norms for simpler tasks such as turning off computer monitors (Miller, 2013), where the expected backlash for not performing is not as high. The role of a specific small, commitment in an anonymous consumption context was evaluated by Baca-motes et al.(2013), with impressive results. They conducted a large field experiment on the tower re-use by 2416 hotel guests over a month. Guests were randomly provided two types of commitment cards to which they can opt to commit: "general" commitment" towards environmentally friendly behaviours or "specific commitment" towards reusing towels during their stay. Later, some of them were additionally given a symbolic 'Friend of the Earth' pin. Results from this 2 x 2 design (with differing specificity of commitment and provision of symbolic pins) reveal that the likelihood of reusing the towels increased in both the commitment cases. However, the guests who made a specific commitment and also received a pin were over 25% more likely to reuse their towels and actually reused 40% towels. They were also found to more likely switch off the lights while leaving their rooms. This provides substantial proof that commitment making, even in the absence of scrutiny may lead to pro-environmental behaviour, and positive reinforcement such as labelling individuals as environmentally friendly can strengthen their commitment.

Commitment, however specific it may be, can only broadly define the general direction for the consumers to do their best in conservation activities. Goal setting, on the other hand, defines tangible reference points to monitor the progress, and is therefore more effective in energy conservation. In one of the foremost of such studies on the effect of setting energy conservation goals, Becker (1978) examined the combined effect of feedback and goal setting on 80 residential households. In the study that ran over 4 weeks in the summer, Becker assigned a "difficult" goal of achieving 20% savings to half the households and a relatively "easy" goal of 2% to the remaining half. In both these groups, half of the households were given indirect feedback on their consumption (as the difference between expected and actual consumption), thrice a week. 20 other households acted as the control group. As expected, the group that received the difficult goal combined with feedback had the greatest savings (13%-15%). No other group consumed significantly lesser than the control. The study concludes that feedback plays a facilitating and motivating role in achieving the set goals. Results obtained from one of the field experiments by Seligman et al. (1978) on 100 households also show that the group which received a difficult goal combined with feedback had more savings (13%) than the group with an easy goal with feedback (4.6%) and the control group. The persistence of the savings could not be verified in either of the studies. The durability of the joint effect of goal setting and feedback was examined in another field experiment by van Houwelingen and van Raaij (1989). 325 households were assigned a 10% conservation goal in their consumption of natural gas. Five groups of 55 households each were assigned to different conditions of feedback frequency and information provision. 50 households were assigned to the control group. The largest energy savings (12.3%) were generated by the group that received daily feedback with the electronic indicator in combination with specific information on how to conserve energy. Results provide strong evidence that feedback and information provision help the consumers learn on their progress and to feel intrinsically rewarded on successfully reaching the defined goal.

Literature also describes the nature of the goals that are most effective for energy conservation. Results from a lab experiment by McCalley and Midden (2002) shows that both self-set and assigned goals are equally effective in energy conservation. However, a clear distinction can be made on whom they have the maximum impact. Evidence from the experiment suggests that "pro-self" individuals conserve more when allowed to set their own goal and that "pro-social" individuals conserve more when they are assigned a goal. Results from another laboratory experiment (McCalley & Midden, 2003) on programming a thermostat for maximum savings reveal that a more specific goal when combined with highly specific information on how to achieve the goal led to higher energy savings.

Literature reviewed also warns us against setting unrealistic goals. Harding and Hsiaw (2014) conducted a cohort study on a particular set of consumers who opted for a pilot study conducted by their electric utility. Once a consumer opted in through a website, she had to set an individual goal for herself from a set of options labeled "No cost", "Low cost" and "High investment" corresponding to around 5%, 10% and 15% savings respectively. Each savings plan had a standard set of energy saving actions, to which the consumer can add extra actions and dynamically set a goal in a given range. Feedback on monthly consumption and all the past monthly electricity bills were accessible in the website. Financial incentives in the form of redeemable "points" were added to consumer's account to promote consumer engagement. While 73% of the consumers set realistic and optimistic goals, 15% chose to set their goal at the bare minimum and about 12% get extremely difficult goals. Analysis of savings over a span of 18 months post the goal-setting show that only those who chose realistic goals had sizeable savings of 11%, while those with very low or impossibly high goals has no significant savings. Financial incentives were found to have a negligible role in influencing consumer actions towards achieving the goal. The non-experimental nature of the study prevents a causal analysis of the large variations between the groups.

The effectiveness of setting group goals was evaluated by a few studies. In two separate experiments by Slavin et al. (1981) apartment residents who were subjected to a group goals in combination financial incentives has shown 6.2%-6.9% savings. The savings from of goal setting alone could not be distinguished; neither could the persistence of savings be evaluated. A quasi-experiment based on an energy competition for school children (Agarwal et al., 2017) too had positive results. The experiment evaluated setting of group goals to 60 primary and secondary schools in Singapore. Children were assigned a goal to reduce electricity usage at home by 10%. Results of the study indicate that families living within 2 km from participating schools showed a 1.8% reduction during the intervention months, which diminished to 1.6% later on.

### 2.2.9 Combinations of interventions

A vast majority of studies used more than one type of intervention. Information provision and feedback were commonly combined with other types of interventions. Providing tailored, real-time feedback often significantly enhanced the effectiveness of interventions such as goal-setting, social norms and message framing. Financial incentives, on the other hand, often worked best on its own and sometimes back-fired when combined with normative influences. Utility programs that targeted communities through a combination of behavioural interventions and energy upgrades evidently led to a higher engagement with the consumers and large energy savings (Kraus, 2014), although the exact impact of the interventions alone could not be gauged in such studies. When targeting long-term, persistent changes to consumption behaviour, invoking a “foot-in-the-door” technique with incremental requests to the consumers was found to be more effective, rather than persuading them for one single large commitment (Katzev & Johnson, 1983). Introducing social interaction among participants led to more engaged participation (Staats, Harland, & Wilke, 2004) and more durable impact of the interventions.

## 2.3 Energy Savings and Durability of the interventions

A wide range of interventions and intervention combinations for behavioural change were found in literature. Although their effectiveness in achieving energy savings is irrefutable, the expected savings from adopting those interventions in the field is arguably much lesser than the claims made by the studies reviewed. Many of the interventions were run for short durations of about a few weeks or months; and in most cases were tried on a low number of households/participants. Most of the studies did not test the durability of the impact with a follow-up examination and therefore could not reveal how much of the effect, if any, persists after the interventions were removed.

We analyzed a subset of 18 case studies over the time period 1976-2017 (Figure 2), that evaluated the impact of feedback with/without social norms/goal-setting, on household consumers and quantified the energy reductions obtained. Maximum short-term energy savings reported shortly after the interventions were introduced varied from 3% to 24.3%, with a median of 5.5%. Only 10 of these studies continued the interventions beyond the initial study period and evaluated their longer term impact. Longer term savings reported with continued intervention were 0% to 23%, with a median of a mere 2.1% in savings. Only one study has shown a net increase in savings in the longer term. In a 3-year longitudinal study, Staats et al. (2004) observed that when subjected to an "intervention package" combining information provision, real-time feedback and social interaction, participants selected for an Eco Team Program (ETP) were able to change 19 of the identified 38 household behaviours in an environmental direction, with a marked reduction in four measures of resource use by the end of the 8 month program. These savings were retained or increased further during the subsequent 2 years. However, it could be noted that the stringent eligibility criteria used for participation in the ETP meant that only 20% of the sample were found eligible to participate. This casts serious doubts on the applicability and scalability of such programs for general population. Although the interventions and the experiment contexts in each of the studies were different, the stark contrast between the short-term and longer-term impacts shows that the reported savings in most studies should not be taken literally, before examining if the impacts are scalable and applicable to larger populations.

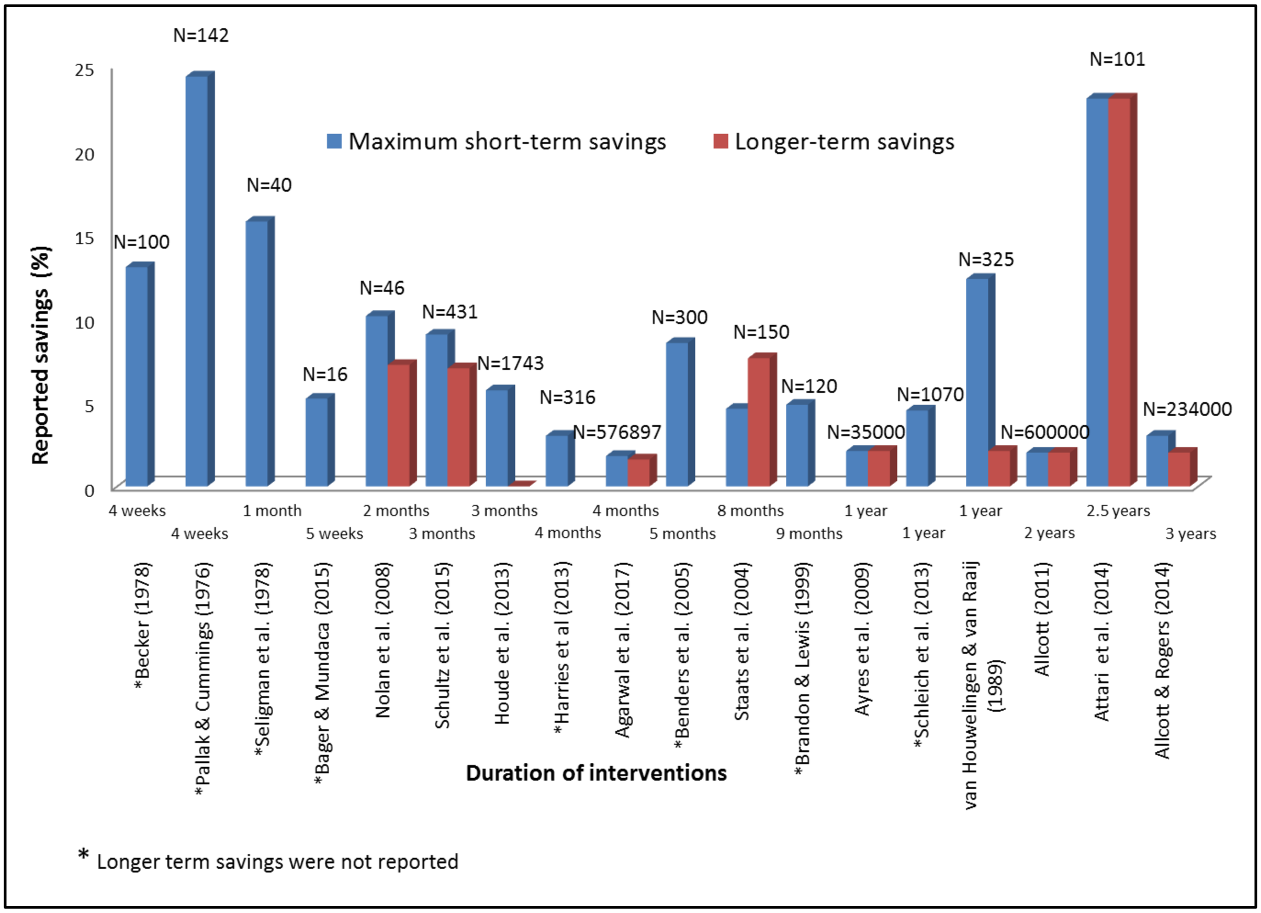


Figure 2: Savings reported in a selection of studies

The duration of the experiments too had a strong impact on the reported savings. Studies with interventions running for less than 4 months (7 out of 18 studies) reported median savings of about 10.1%, while longer duration studies reported only about 4.5% of median savings. All the four studies that dated before 1990 reported savings in excess of 10%, three of which did not review longer-term savings. Savings reported by newer studies, on the other hand, was much mellowed down and are more realistic in comparison. Only one recent study that tested the effect of disaggregated feedback by installing plug-level devices (Attari et al., 2014) reported savings in  excess of 20%. Compared to other feedback studies, treatment in this particular study (installing several plug-level devices in customer premises) was highly intrusive. In addition, the opt-in nature of participant selection, the frequent reminders to install measurement devices and regular face-to-face interactions with other participants could have resulted in electricity consumption being much more salient than in any regular setting. Finally, the experiment was conducted in a brand new, energy-efficient (LEED Gold-rated) building, where most of the participants have recently moved in as tenants. All these factors make this experiment an exception to the normal, with reported high savings unlikely to be replicable in other situations. Evidence from literature suggests that real-time feedback from smart energy monitors gradually gets "backgrounded" with normal household behaviours (Hargreaves et al., 2013) and the high savings initially reported could taper down along with the novelty of the device.

The sample size of the treatment and control groups had a dominant role on the reported energy savings. Studies conducted on low number of participants/households reported larger savings, while studies conducted on larger samples (hundreds of thousands of consumers) reported far lesser savings and lesser standard errors. For instance, one of the earliest studies on the impact of indirect feedback and goal setting (Becker, 1978) was conducted on merely 100 households and reported 13% savings. A high variation in the impact of the intervention observed between different types of households. The study was conducted during one month in summer, when electricity consumption is at its peak. It is highly likely that consumers could have temporarily altered their behaviour due to their awareness of being part of a study. Hawthorne effect could have had a significant impact for a study conducted over such a short span. In contrast, studies that analyzed the Opower's programs implemented in several thousands of households (Allcott, 2011; Allcott & Rogers, 2014; Ayres et al., 2009) reported far lesser savings —between 2%-3%— that could be sustained for years if the interventions continued.

Many of the studies reviewed have a few fundamental drawbacks in their experimental designs, and in their savings estimates. This could have potentially led to over-estimation of the potential impact of individual interventions. For instance, Nolan et al. (2008) has compared the savings generated by a combination of feedback and social norms and fail to distinguish the impact of each intervention separately. A clearly defined control group is absent in many studies. A study by Gans et al. (2013) had compared groups receiving real-time feedback via keypad meters with other groups that didn't have keypad meters. However, another key feature of the treatment group was that households in this group were enrolled in pre-payment plans. This makes it impossible to differentiate between the effect of the intervention and the effect of the pre-payment mechanism. Almost all the studies failed to mention how exactly the households managed to generate savings, and the specific household behaviours that were influenced by the interventions. While a few studies studied the effectiveness of continued intervention, most of the interventions failed to examine whether the newly formed habits could be retained after the intervention has been completely removed. All this indicate that the savings reported in the experimental conditions are mainly based on short-term interventions that did not consider the long-term behaviour change and habit formation due to the interventions. Policy makers must realize that such figures are highly optimistic and must therefore consider only longer term estimates derived from at least a year of continued observations on larger and diverse samples of population.

## 2.4 Groups targeted by the behavioural interventions

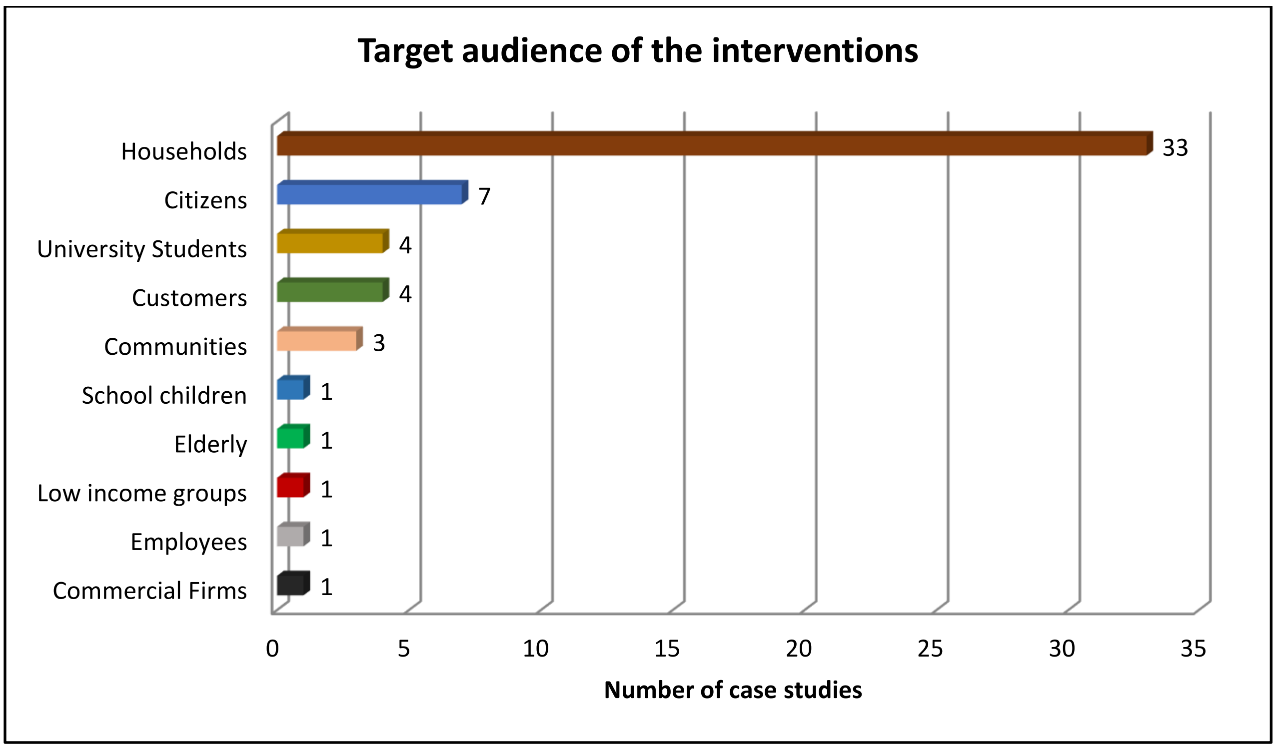


Figure 3: Audience targeted by the behavioural interventions

A vast majority of selected studies on behaviour interventions targeted regular households, with sample sizes for the interventions varying between 16 to 600,000 households. The reported savings during the treatment period too varied widely ranging 1% to 23%, depending on the type of intervention provided, the appliances being used, seasonal factors and the demographic characteristics of homeowners. Evidence from many studies suggests that not all households respond uniformly to the same interventions. For instance, Schleich et al. (2013) find that the effect of feedback was found to be statistically significant only to the consumers in the 30th – 70th percentile of consumption. Attari et al. (2014), who reported the highest persistent savings (23%) with disaggregated feedback observes that most of the savings potential is concentrated in the households who had a higher willing-to-pay for the energy monitoring systems. Environmental and health-based message framing on families with children was found to be twice as effective as on regular households (Asensio & Delmas, 2015). Social norms were found be more effective for households with liberal political ideology (Costa & Kahn, 2013). Effects of social comparison were observed to be much less noticeable in low use households, in a developing country (Pellerano et al., 2016). All this suggests that socio-demographic characteristics affect the energy savings substantially. Therefore, multiple regression analysis to test the influence of all contextual variables could have potentially influenced the savings potential is absolutely essential. Where possible, profiling of consumers with pro-environmental attitudes help to better understand the exact causes that led to the behavioural changes.

Studies that targeted entire communities (as opposed to targeting individual households) have often employed a range of conservation measures and had multiple overarching objectives such as peak-load reduction, job creation and community participation. Savings reported by such studies encapsulate the combined impact of energy audits, home energy upgrades, competitions, media campaigns, in addition to behavioural interventions. Nevertheless, evidence from the three studies reviewed (Attari et al., 2014; Kraus, 2014; Slavin et al., 1981) attests the phenomenal success of such larger, community-focused group contingency interventions in engaging with the consumers, in increasing their awareness of energy behaviours and in initiating interactions about energy conservation. Nudging schoolchildren is another way in conveying the conservation messages to families and neighbors (Agarwal et al., 2017), but the quantifiable impact of such measures was found to be contestable in such cases. The influence of 'nudged' children on household's consumption was difficult to be distinguished from other extraneous factors that could have potentially led to energy savings.

Studies that targeted university students have conducted experiments to explore the effectiveness of conservation appeals, advertisements, petitions and competitions on individuals. While the validity of the results of such experiments is undebatable, their applicability to a more heterogeneous population needs to be considered with caution. Similarly, studies that recruited representative citizens, often through advertisements, inadvertently over-represented more educated individuals who tend to be more biased towards efficiency measures and more capable of operating energy appliances. Individual differences among participants could manifest in varied savings rate amongst them. For instance, users subjected to a computer simulation of thermostat programming An online survey by Van de Velde et al. (2010) shows that among representative individuals, men, higher educated people and people between 35 and 54 years age are less affected by message framing. Such differences in individual capabilities to respond to behavioural interventions could be explored further by the utilities, possibly with pilot studies, prior to roll-out of expensive "smart" energy devices, plug-level energy monitoring devices and detailed Home Energy Reports (HER).

The practical application of behavioural interventions for influencing customers' purchase decisions was proven by four studies. Kallbekken et al. (2013) and Anderson and Claxton (1982) show how interventions targeting potential customers can influence the purchase of efficient appliances. The influence was found to be stronger in the purchase of smaller appliances (Anderson & Claxton, 1982), suggesting the role of willingness-to-pay as a catalyst or a moderator for such influences. Potential customers of energy retrofits were found to be influenced by loss-based framing (Gonzales et al., 1988) and displayed a higher likelihood to apply for utility's finance programs. Conducting similar experiments on financing of energy retrofits for large commercial firms and buildings can pave the way to more substantial savings in energy and carbon emissions. Interventions that targeted specific high impact behaviours of customers, such as reusing towels in hotel (Baca-Motes et al., 2013), resulted in larger savings as compared to those that targeted generic conservation behaviours.

An intriguing challenge to behavioural interventions is their applicability to the energy poor. Economically disadvantaged people such as the elderly and low income groups usually consume lesser than the average population and are more sensitive to price changes. They tend to be much more focused on the present and have much higher discount rates than the normal. Cash transfers that the government issues to the energy poor to enable them in purchasing efficient fuels often get used for other causes. By positively utilizing the “mental accounts” of the elderly for fuel purchase in the UK, Beatty et al. (2014) show that a conspicuous labeling of the cash transfer as “Winter Fuel Payment” can increase the likelihood of purchase of a more efficient fuel by 44%. Based on her review of efficient lighting in three African countries, Never (2014) explains why energy efficiency occupies a low priority for the poor. Interventions that target the poor must strive to increase the perceived social affordability, financial affordability and the social acceptance of the product. As opposed to merely targeting energy efficiency, products and services that aim to win the trust and increase the status of the poor, while considering the local norms, are bound to be more successful in poorer economies. Interventions that frame the gains and losses in the present timeframe, and energy savings framed in more tangible terms such as “equivalent of 1 kg of cassava a month” tend to be more impactful for the poor (Never, 2014). Framing messages that utilize loss aversion are found to be much more favorable in influencing the behaviour of the poor to adopt energy efficient lighting. Most of the studies targeting energy behaviour have been disproportionately focused towards the developed world, and scant literature exists on the application of behavioural economics specifically targeting the energy poor. However, with the bulk of economic development and growth in energy use expected to come from developing countries in forthcoming decades, it is highly imperative to conduct many more behavioural experiments and analyze what works best for the energy-poor, particularly in the developing countries.

Commercial entities and employees are perhaps the most difficult to get affected by behavioural interventions. Employees are often disconnected from the impact of their energy use in offices and are therefore disinterested in changing their behaviours. Interventions targeting office employees must therefore firstly make the consumption behaviours more prominent to the employees. Exploiting public commitment and social norm activation for specific consumption tasks such as switching off computer monitors was found to be fruitful in a study on employee engagement for energy conservation in office buildings (Miller, 2013), although the long-term habit formation of such behaviours were not discussed. Utilizing the importance given by commercial and industrial firms to public perception, Shippee and Gregory (1982) studied the impact of public commitment on energy savings in 16 small commercial-industrial firms. Thoughtful selection of only locally-owned firms ensured that the firms really cared about the public commitment they made. Results from their study suggest that the firms really cared for their public image but could generate savings only in the case of a lower, realistic commitment. The authors advocate against expecting similar results for outlets and stores of larger firms, who probably would care neither for public advertisements in local media nor for the relatively smaller savings achieved. With commercial and office buildings being the among the largest energy guzzlers in many countries, any behavioral interventions that cater specifically to high energy consumption behaviours in these buildings could potentially lead to huge energy savings.

## 2.5 Discussion

The systematic review of the 56 studies using six distinct criteria revealed several interesting insights on the application of behavioural interventions for energy efficiency. Reviewing the experiment designs utilized in the studies showed a clear preference for quantitative approaches over qualitative approaches. Classical experiments with randomized controlled field trials were the most preferred type of design. We find that combining these with a qualitative feedback from the subjects of experiments would strengthen and validate the results obtained. More observational and longitudinal studies could help decipher the contextual factors in the energy consumers' decision making. We propose that at a minimum, an experiment should have well-defined control and treatment groups, a proper baseline measurement before the intervention, a random selection of participants, less intrusive monitoring, measurements both during the intervention period and long after the intervention has stopped and multiple regression analysis to test the influence of all contextual variables.

Broadly, seven different intervention types were observed in the studies. Information provision and feedback were noted to be the most commonly used. We find that the most productive type of feedback is the one that is the most instantaneous, frequent, tailored, interactive, disaggregated and salient. We propose that all new measures and policies to roll out "smart" devices in consumer premises must first ensure that the feedback provided is relevant, useful, intelligible and easy to interpret, to gain the consumers' trust and involvement. We question the effectiveness of financial incentives and recommend that the cost-effectiveness and durability of financial incentives must firstly be justified before being adopted by energy policies. In contrast, we find message framing and choice architecture to be more cost-effective and consistent in generating durable energy savings.

We analyzed the durability of reported savings and found that studies with low sample sizes and shorter duration of experiments could have potentially over-estimated the long-term savings potential of the interventions.  We recommend that policy makers must consider only longer-term estimates derived from at least a year of continued observations on larger and diverse samples of population.

Finally, we analyzed how different targeted audiences responded to different behaviour interventions. We note the potential for behavioural interventions targeting commercial firms and acknowledge the critical need to find what works best for the energy-poor and the disadvantaged.

# Chapter 3: To upgrade or to wait? Exploring the role of procrastination trait in upgrading energy-efficient refrigerators

## Chapter Abstract

The impact of individual behavioural traits on the effectiveness of energy policy has been studied. We conducted a Randomized Controlled Trial field survey to identify procrastination behaviour in residential consumers in upgrading to energy-efficient refrigerators and attempted to treat it using a behavioural experiment. Residential consumers in Singapore were requested to fill a web-based survey. Respondents were randomly distributed into Treatment and Control categories – with and without information on the cost of delay. Analysis of the results revealed that the relationship between self-reported procrastination score and delay chosen for appliance upgrade exhibits a slight positive correlation, albeit statistically insignificant. The Treatment (providing information on loss due to inaction) has a high and statistically significant impact on intended delay in upgrade of refrigerators. The impact of demographic characteristics of participants on the delay in intended purchase was analysed. More educated people are found to be less present-biased than lesser educated ones and hence could take better decisions on energy efficiency upgrades. The results suggest that consumers' procrastination in appliance upgrades can be overcome by highlighting the costs of delayed action. Implications of the findings for replacement purchases of appliances in developed countries are discussed.

## 3.1 Background

Residential households consume 15% of electricity in Singapore and contribute up to 8% of total GHG emissions (EMA, 2016). This electricity consumption by households has been increasing steadily at an annual growth rate of 1.6% in the past decade. Roughly 59% of the total 7.221 GWh of residential electricity consumption is by public housing units, while the rest is by private housing. While the average monthly consumption by private household has shown a slight decreasing trend in recent years, the consumption by public housing dwellings has registered a 1.2% growth year-on-year.

Refrigerators are among the top three energy guzzlers in Singaporean homes and account for about 18% of the total household electricity consumption, after air conditioners and water heaters (NEA, 2012). Aside from significantly contributing to the electricity bills, the refrigerants leaked during the operation and disposal is a severe contributor to global warming. Also, aging of the refrigerators reduces their efficiency and further increases the electricity used. Therefore, upgrading to more energy-efficient refrigerators offers among the highest potential for energy savings for residential consumers.

Accordingly, the Singapore government had introduced the Minimum Energy Performance Standards (MEPS) in 2011 for household air-conditioners and refrigerators to help consumers avoid being locked into high energy consumption and costs of the most inefficient appliances. Although this policy enables consumers to purchase only those appliances that meet minimum standards, it does not incentivize them to replace their old and inefficient appliances. In the absence of incentive schemes targeting residential consumers, the decision for replacement of inefficient appliances rests solely on the consumers' capability and willingness to make energy efficiency purchases. However, findings from a household energy efficiency study (MEWR, 2013) reveals that many residents opine that energy efficient appliances are expensive and that they lack crucial information such as annual/life cycle energy consumption that can aid consumers to make informed purchased decisions. Critical obstacles that prevent households from making energy efficiency purchases include a lack of immediate capital, inability to estimate pay-back periods and very often procrastination of cumbersome tasks to a distant future (Lillemo, 2014; MEWR, 2013).

Intertemporal choices such as investing in energy-efficient appliances involves trade-offs between the present investment costs and the future benefits, usually spread over several months or years. Contrary to normative economic theory on intertemporal choice, behavioural economics reveal that consumers often behave “irrationally” by making suboptimal choices and tend to systematically deviate from standard economic models by displaying excessive “discounting” behaviour. That is, consumers undervalue (discount) their future costs and benefits and overweigh the present cost and savings. Such high discount rates are considered in behavioural models for energy investment as an implicit representation of uncertainty, information gaps and bounded rationality, part of which could possibly be corrected with behavioural interventions. One possible explanation for a high discount rate is given by the IPCC in the fourth assessment report (Halsnæs et al., 2007) by stating that “for mitigation effects with a short-term horizon, a country must base its decisions (at least partly) on discount rates that reflect the opportunity cost of capital”, and these could be as high as 10% to 25% for private investments.

Previous estimates on implied discount rates that were derived from laboratory experiments were simpler in design and mathematically accurate in estimating the discount rates by observing choices made between pairs of alternatives. However, these studies fail to factor in the complexity of real-life decision making where the choices are rarely binary. Nevertheless, these studies facilitated to understand the behavioural phenomena involved in decision making. Another common feature of previous studies is that they have assumed that the investment decision is made in the present, while the benefits (energy savings) are expected in the future. The temporal aspect of the consumer’s decision itself was not considered in estimating the discount rate. In contrast, this study tries to estimate the implied discount rate using the consumers’ “intended delay” in upgrading their inefficient appliances.

### 3.1.1 Procrastination trait and its impact on energy efficiency

*Procrastination*—the tendency to keep postponing tasks/decisions that require effort is an extremely prevalent and growing phenomenon (P. Steel, 2007). Behavioural economics alludes to it as an irrational delay in taking decisions, despite being worse off for the delay. Literature points to this behavioural trait as a self-regulatory failure affecting about one-fifth of the adult population and half of student population (Rozental & Carlbring, 2014) . Studies also indicate that it may be prevalent across diverse populations in spite of their distinct cultural values, norms, and practices(Ferrari, Díaz-Morales, O'Callaghan, Díaz, & Argumedo, 2007). Numerous studies in literature discuss the detrimental effects of procrastination on academic performance, work productivity, financial and subjective well-being (Klingsieck, 2013). Consumer's procrastination, in particular, was analysed using two dimensional construct: indecision and avoidance to make a planned purchase (Darpy, 2000).

Procrastination can hinder both energy efficiency purchases and energy curtailment behaviour (Lillemo, 2014). Such postponement of energy efficiency decisions has severe detrimental effects on both the environment and the economy. Literature suggests that mere environmental awareness and information provision on energy saving could lead to positive intentions, but not necessarily to pro-environmental behaviours (Kollmuss & Agyeman, 2002; Lucas, Brooks, Darnton, & Elster Jones, 2008). This is because the positive effect of environmentally friendly intentions might get moderated by the tendency to procrastinate in energy-saving practices or purchases. While everyone procrastinates to varying degree in daily life, some people could be habitual procrastinators who procrastinate even critical tasks pathologically. However, energy policies treat all consumers as equally capable of making purchase decisions, without acknowledging such procrastinating consumers with irrational delay behaviour. Therefore, to realize the full potential of energy efficiency, it is important to identify such irrational procrastination behaviours and to treat them through appropriate interventions. One such possible treatment includes finding ways to either bring future benefits closer to the present or to magnify the costs of delayed action (Lillemo, 2014)

### 3.1.2 Measuring Procrastination

Despite the rising recognition of the prevalence of procrastination, deriving valid and repeatable methods of measuring procrastination has proven to be challenging (P. Steel, 2010). Measurement of procrastination is mostly based on self-report measures, each stemming from different theoretical frameworks (Rozental & Carlbring, 2014).Some measurement scales for procrastination trait include the Decisional Procrastination Questionnaire (DPQ; Mann, 1982, unpublished) , Lay's (1986) General Procrastination Scale (GPS) encompassing 20 items of measurement, Aitken's Procrastination Inventory consisting of 19 items(API) (Aitken, 1982), Tuckman (1991) Procrastination Scale (PS), each testing for arousal/sensation seeking and task avoidance constructs of procrastination in students and adults. Steel (2002)designed a scale explicitly for the measurement of irrational delay based on 9 items, called the Irrational Procrastination Scale (IPS). A meta-analysis on studies for procrastination as well as a confirmatory factor analysis (CFA) by Steel (2010) revealed that only some of items being measured in existing scales accounted for most of the variance. He therefore introduced a new scale based on 12 items derived from the most relevant items from existing scales – the DPQ, GPS and the AIP and named it as the Pure Procrastination Scale (PPS). PPS, which has proven reliability and consistency in procrastination research studies on adults in multiple countries and cultures (Rebetez, Rochat, Gay, & Van der Linden, 2014; Rozental & Carlbring, 2014; Svartdal, 2015) is chosen for this study. Reasons to choose PPS include its ease of use in survey and its effectiveness to measure procrastination as an irrational behaviour.

### 3.1.3 Innovative value and relevance of the study

Although the literature on procrastination is vast and varied, its impact on energy efficiency in residential buildings is less studied or understood. While energy policies consider that increasing environmental awareness by itself can invoke energy saving behaviour, it is most likely that the magnitude of such positive change is moderated by the procrastination trait of individual consumers. However, energy policies until now consider purchase of energy efficient appliances as a binary choice— the temporal aspects of the purchase or enrolment, i.e. of taking the right decision at the right time is often overlooked. This study aims to fulfil this gap by testing the impact of procrastination on appliance upgrades. To our knowledge, this is among the first such studies on identifying procrastination of residential energy efficiency purchases and attempting to treat it using behavioural experiments.

## 3.2 Objectives of the study

The scientific objective of the study is to verify if residents of Singapore who postpone their decision to replace inefficient refrigerators, do so because of severe procrastination traits. Further we investigate if such irrational procrastination could be corrected by behavioural interventions that frame distant benefits of positive action and the loss due to inaction in the present time context.

For the government/society, our objective is to provide guidance to energy policy makers and energy system operators about - how to design effective energy efficiency policies that factor in irrational behavioural traits in few of the consumers.

### 3.2.1 Hypotheses:

**Hypothesis 1:** *Procrastination* trait negatively moderates the effect of energy labels on changing consumers' behaviour for refrigerator upgrade.

**Hypothesis 2:** Framing the monetary cost of delay to replace an inefficient refrigerator, in the present time, would expedite the replacement of refrigerator for a habitual procrastinator.

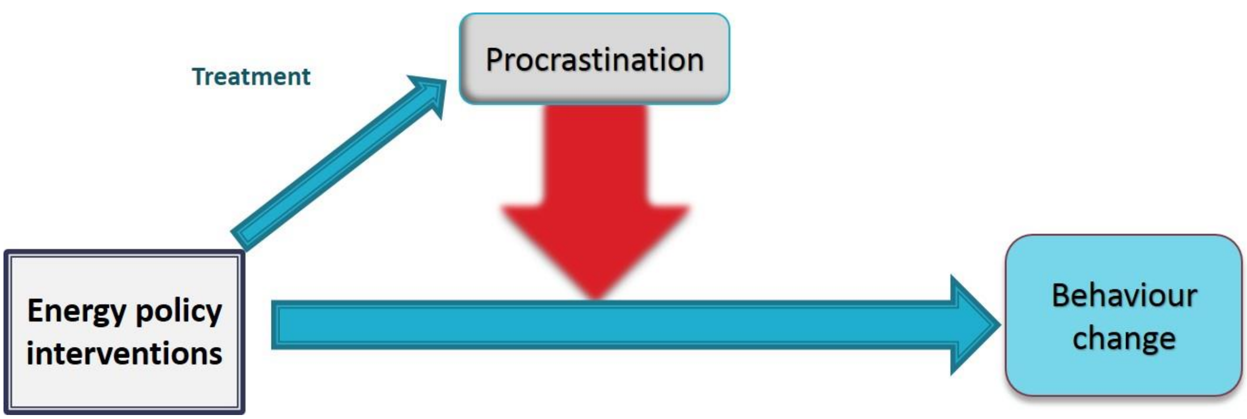


Figure 4: Illustration depicting the hypotheses

## 3.3 Materials and Methods

### 3.3.1 Participants

Residential energy consumers who are residents of Singapore and living in primarily two residential areas were targeted for the survey using flyers delivered door-to-door and posters in public places such as community centres. Two preliminary surveys were initially conducted on small sample sizes (N=17; N = 13) to verify the willingness to upgrade electric appliances and to validate the suitability of PPS to measure procrastination. Results from the preliminary surveys suggested that many residential consumers in Singapore use their air conditioners sparingly, and therefore are not too concerned in upgrading to more efficient ones. However, most households were found to possess inefficient refrigerators, bought prior to 2013 (when MEPS was last revised), hence the final survey was focussed solely on upgrading refrigerators bought prior to 2013. PPS, with only 12 questions was found to be easy to use and procrastination score had shown positive correlation with the delay chosen for appliance upgrade. The preliminary surveys also enabled us to organize the questions for the final survey and to set eligibility criteria for participation in the survey. To maintain homogeneity, a preliminary check was performed before the final survey to ensure participants' Singaporean residency as well as their possession of an old (5 years or older) refrigerator. Survey responses were collected over three weeks between end of July and beginning of August 2017. Of the 2000 plus residential consumers targeted, 249 responded, of which 168 responses were found to be complete and valid. 15 of the 168 respondents displayed an unwillingness to upgrade their refrigerator in foreseeable future; these responses were excluded from further analysis.

The survey was conducted using *Qualtrics*, a well-known web-based software used for academic research accessible on Desktops and Tablets. Participants were informed about the voluntary nature of the survey. Completion of the survey generally took 10-15 minutes and a nominal incentive of S$ 5 in the form of a gift voucher was given for participation.

### 3.3.2 Ethics

The study on which this chapter is based had received ethical approval from the Institutional Review Board of the National University of Singapore and conforms to the guidelines for "Social, Behavioural and Educational Research". Participants were informed about the voluntary nature of the survey. Completion of the survey generally took 10-15 minutes and a nominal incentive of S$ 5 in the form gift voucher was given for participation.

### 3.3.3 Experiment Design

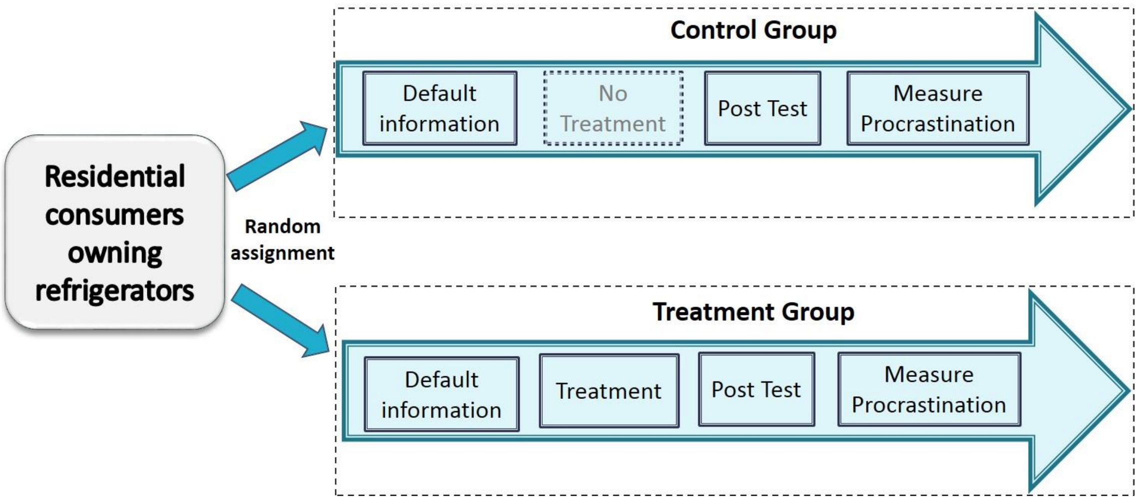


Figure 5: Procedure for Randomized Control Trial

A Randomized Control Trial (RCT) field experiment was conducted by randomly assigning the participants into a Control and a Treatment group, as shown in **Error! Reference source not found.**. Participants from both groups were shown same web pages about the initial cost of an efficient refrigerator and the difference in operating costs of an inefficient refrigerator and an efficient one. The treatment group was shown an extra web page visualizing the monetary cost of delay. (Appendix B)

**Control Group (Default information page):**

The participants were shown a comparative cost data sheet displaying details of energy consumption and life cycle costs of an 8-year old, inefficient (zero green ticks) refrigerator compared to an efficient (3 ticks) one. Representative data for 3 different sizes of refrigerators typically used in Singapore's public housing flats (Appendix B) was displayed along with their energy consumption and life cycle costs (LCC). Cost of replacing an 8-year old air inefficient refrigerator with an efficient one is highlighted, along with the savings expected over the life time (10 years).

Data on the representative sizes, the number of green ticks, annual energy consumption and energy costs are obtained using the Life Cycle Cost Calculator provided by the National Environmental Agency (NEA), with slight modifications to suit this experiment. The lifetime energy consumption and costs are calculated for three distinct refrigerator sizes. Typical costs of refrigerators were obtained from two popular commercial websites, www.lazada.sg and www.gaincity.com . To remove the effect of variation of lifetime costs for different brands, models and sizes of refrigerators, care is taken to display the costs of only three most widely used refrigerator sizes of a popular brand while highlighting only the median values for each size. Assumptions made in refrigerator LCC calculation are also displayed separately to the consumer (Appendix C).

**Treatment Group (Additional information page):**

In addition to comparative cost data sheet, the treatment group was shown a page that frames the cost of delayed decision as a loss. This page explicitly displays the financial benefits of replacing an inefficient refrigerator, and the cost of not taking any action within the following 6 months, one year, two years and five years. In addition, a lucid statement was presented stating that the longer the upgrade is delayed, the more electricity and money is wasted. Thus, the temporal aspect of procrastination is displayed both graphically and in wording to the consumer.

Consumers from both the Control and Treatment group are then posed a question if (s)he is interested in replacing the inefficient refrigerator and a realistic time frame when (s)he will do it. A graphical slider was provided for the customer to choose a future month/year counting from the present.

### 3.3.4 Measures

The next stages of the procedure are the measurement of procrastination, followed by questions on socio-demographic information, details of the housing type, appliance usage and their average electricity bill. Participants were informed that the purpose of the questions was to understand the barriers for consumers' decisions for appliance upgrade and were requested to answer all questions.

**Procrastination:**

The Pure Procrastination Scale (PPS), which has proven reliability and consistency in procrastination research studies on students and adults in multiple countries and cultures (Rebetez et al., 2014; Rozental & Carlbring, 2014; Svartdal, 2015) is chosen for this study. The PPS is a self-report measure scored on a 5-point Likert-type scale ranging from 1, extremely uncharacteristic, to 5, extremely characteristic (Appendix D). All items are consistent with the perception of procrastination as an irrational delay. Unlike other scales designed for academic procrastination, this scale was developed for participants from the general population and is more suited for our purpose.

**Socio-demographics:**

Studies on procrastination have attempted to study the impact of demographic indicators such as gender, age, marital status, income, education and community location, with inconclusive or often contrasting results. Literature also suggests task deferment shown by procrastinators due to perceived lack of self-efficacy and self-doubt. In households, often in such cases, the decisions are either postponed indeterminately or get delegated to someone perceived to be more suited. The individual's role in taking financial decisions such as buying a new appliance, can therefore be a critical parameter to measure. Respondent distribution on age, income and education (shown below) are found to be representative of middle income, Singaporean adult population. The number of female respondents (N=94) was greater than the males (N=59).

**Data processing**

After data collection, firstly, we eliminated responses from individuals who do not meet the entry criteria such as age (respondent must be 18 or older), Singaporean country residency and owning a residential flat. Responses were then screened for duplicates based on the IP address of the online response and the demographic and housing information submitted in the survey. We then eliminated incomplete responses and responses from individuals owning refrigerators lesser than five years old. Further, eliminating nonsensical responses such as those with gibberish entry left us with 168 valid responses. 15 of the respondents displayed an unwillingness to upgrade their refrigerator in the foreseeable future, these responses were noted, and excluded from further analysis on delay chosen for appliance upgrade.

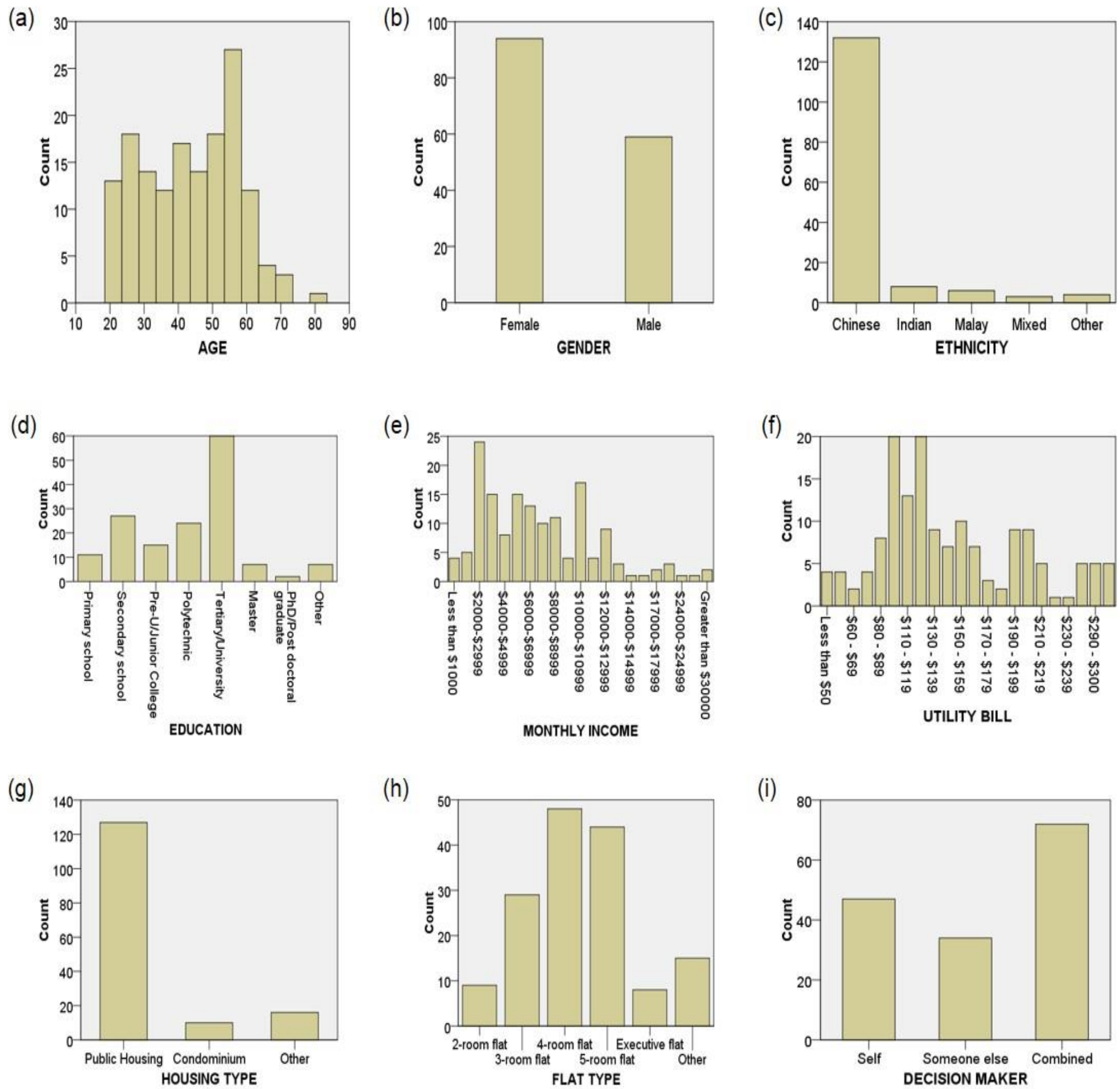


Figure 6: Demographic characteristics of respondents

## 3.4 Results

### 3.4.1 Descriptive statistics

Respondent distribution on age, income and education (shown below) are found to be fairly representative of middle income, Singaporean adult population. The number of female respondents (N=94) was greater than the males (N=59).

The procrastination scores of both the Control group and the Treatment group showed a similar distribution, roughly centred around 30 as the mean procrastination score for the samples, suggesting the homogeneity of the respondents among two groups.

Table 3: Descriptive statistics

| | | Mean | Median | STD. DEV | N |
|---|---|---|---|---|---|
| **Control** | **Procrastination Score** | 29.37 | 30 | 6.87 | 73 |
| | **Delay** | 39.68 | 36 | 20.26 | 73 |
| **Treatment** | **Procrastination Score** | 30.56 | 29 | 7.54 | 80 |
| | **Delay** | 31.08 | 26 | 18.12 | 80 |

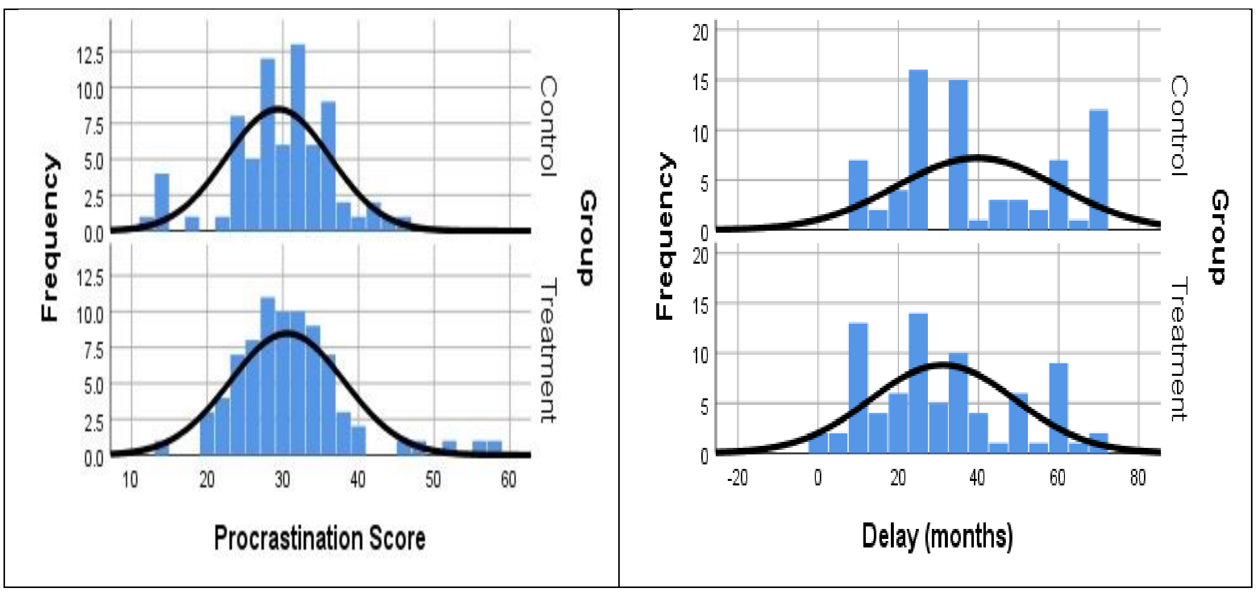


Figure 7: Participants' procrastination scores and the delay chosen for refrigerator upgrade

### 3.4.2 Procrastination score and the delay in upgrade

Both the procrastination and delay were numerical inputs in interval scales. Hence, we tested for correlation using the Pearson correlation test. Although the relationship shows a positive correlation in both Control and Treatment groups (r=0.117 and r=0.125), the correlations are weak and not statistically significant to reject the Null hypothesis.

Table 4: Descriptive Statistics

| | | Mean | Median | Std. Dev. | N |
|---|---|---|---|---|---|
| **Control** | **Procrastination Score** | 29.37 | 30 | 6.87 | 73 |
| | **Delay** | 39.68 | 36 | 20.26 | 73 |
| **Treatment** | **Procrastination Score** | 30.56 | 29 | 7.54 | 80 |
| | **Delay** | 31.08 | 26 | 18.12 | 80 |

Table 5: Correlation between Procrastination Score and Delay

| | | Procrastination | Delay |
|---|---|---|---|
| **Control** | **Procrastination Score** | 1.000 | .117 |
| | **Delay** | .117 | 1.000 |
| | Sig. (2 tailed) | | .324 |
| | N | | 73 |
| **Treatment** | **Procrastination Score** | 1.000 | .124 |
| | **Delay** | .124 | 1.000 |
| | Sig. (2 tailed) | | .271 |
| | N | | 80 |

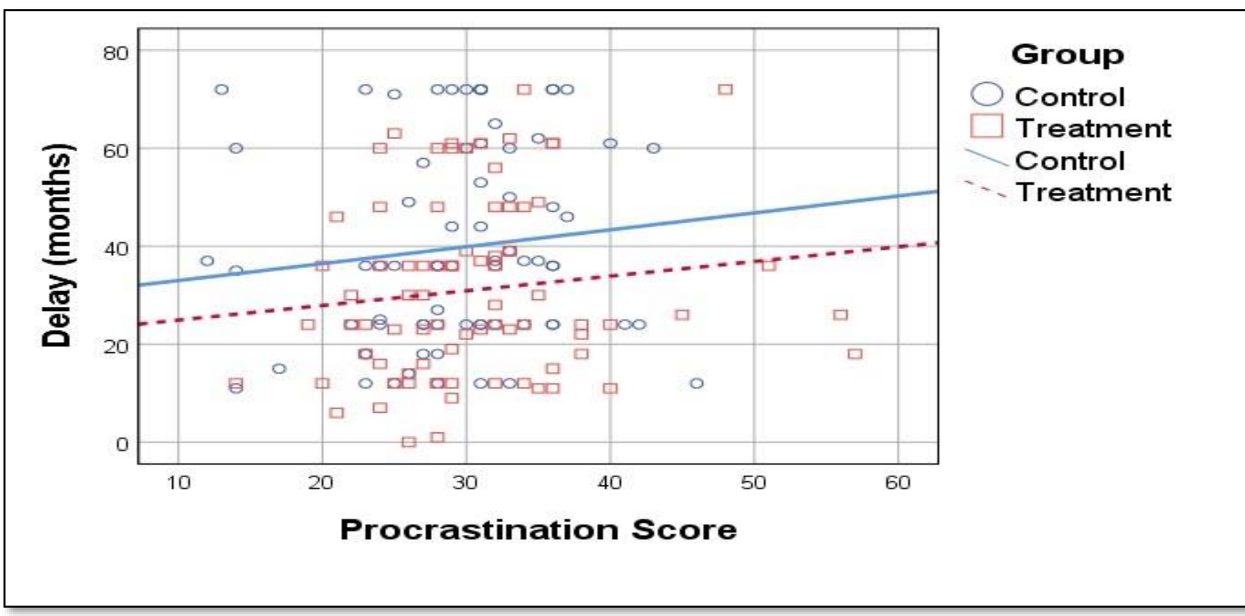


Figure 8: Correlation between Procrastination score and Delay

**Delay for High & Low procrastinators**

Procrastination scores collected from the participants (both Control and Treatment groups) displayed a normal distribution, roughly centred around a mean score of 30 (see Table 4). For the sake of simplicity, people scoring above this mean are classified as high procrastinators and those scoring 30 or below as low procrastinators. We then analysed the differences in mean delay observed in these two groups of participants (see Table 6, Table 7).

Table 6: Group Statistics of High and Low procrastinators

| | Procrastination Score | N | Mean Delay (months) | Std. Dev. | Std. Err. Mean |
|---|---|---|---|---|---|
| High procrastinators | >30 | 71 | 39.06 | 19.424 | 2.305 |
| Low procrastinators | <= 30 | 82 | 31.83 | 19.226 | 2.123 |

Table 7: Independent Samples T-Test for High and Low procrastinators

| | Levene's Test for Equality of Variances | | | | |
|---|---|---|---|---|---|
| | **F** | **Sig.** | **T** | **df** | **Sig. (2 tailed)** |
| Equal variances assumed | .222 | .638 | 2.308 | 151 | .022 |
| Equal variances not assumed | | | 2.306 | 147.442 | .022 |

A t-test on these two groups showed a significant ($p < 0.05$) difference between high procrastinators and low procrastinators for the delay chosen in upgrading to an energy-efficient refrigerator. In other words, a highly procrastinated person would delay longer in replacing existing appliances.

We went on to analyse the impact of other demographic variables such as age, income, gender, marital status and ethnicity on the procrastination scores. Except for the level of education, we could not establish any significant relationship between these demographic factors and the self-reported procrastination value. This could possibly be because consumers' procrastination is being affected by factors other than demographic variables.

### 3.4.3 Other factors affecting Delay

**Awareness of energy labels and Delay**

A clear majority of the respondents are found to be aware of the green tick labelling of electrical appliances (145 out of 153), which shows that the government's awareness campaigns on energy labelling were largely successful in increasing consumer awareness. Nevertheless, mere awareness of energy labels did not have any significant impact ($p > 0.1$ in T-Test) in the consumers' choice of intended delay in appliance upgrade.

Table 8: Independent samples T-Test for groups of consumers Aware and Not-Aware of energy labelling

| | Mean Diff. in Delay | Std. Error Diff | t | df | Sig. (2 tailed) |
|---|---|---|---|---|---|
| Equal variances assumed | -11.725 | 7.518 | -1.560 | 71 | .123 |
| Equal variances not assumed | -11.725 | 7.256 | -1.616 | 8.993 | .141 |

**Education level and Delay**

While collecting demographic information in the survey, participants were given the option to choose their education level from 7 incremental categories that are usually found in Singapore. However, since Singapore is a country with many immigrants having different nationalities, there is a possibility that at least a few of them could be born in a different country and hence could have had a different type of education, we had added an extra category called "Other". Of the 73 respondents, 68 choose from the 7 education categories of Singapore, while 5 selected "Other". These 5 responses were removed from further analysis. Since the education levels are categorized using ordinal scales (from lowest to highest categories), we performed two non-parametric correlations to test the relationship between education level of participants and the delay chosen for appliance upgrade. Both the tests confirmed a negative correlation between education level and delay, with a good statistical significance ($p < 0.05$). Delay chosen for refrigerator upgrade decreases with increase in the level of education. This reveals that more educated people are less present-biased than lesser educated ones and hence could take better decisions on energy efficiency upgrades.

Table 9: Non-parametric correlations of Delay VS Education level (68 samples)

| **Non-parametric correlations** | | Delay | Education Level |
|---|---|---|---|
| **Spearman's rho** | Delay<br>Education Level<br>Sig. (2 tailed)<br>N | 1.000<br>-.186*<br><br>68 | -.186*<br>1.000<br>.048<br>68 |
| **Kendall tau_b** | Delay<br>Education Level<br>Sig. (2 tailed)<br>N | 1.000<br>-.259*<br><br>68 | -.259*<br>1.000<br>.033<br>68 |
| *. Correlation is significant at 0.05 level (2 tailed) | | | |

**Participant's role in financial decisions**

The delay chosen by respondents was found to vary depending on the respondents' role in the financial decision making. Delay was lower when the respondent was the primary decision maker in the household. We went to test if the treatment was more effective on respondents who identified themselves as the primary or sole decision makers in their household. The interaction between Treatment (Control & Treatment) and Decision maker (Self & Others) was tested with a 2x2 ANOVA test. However, results showed that for, the difference in delay for different decision makers was statistically significant ($p < 0.05$) only between the treatment groups (Control vs Treatment) and not between decision maker groups (primary and non-primary decision maker). Also, the interaction between decision categories and treatment categories was not significant ($p > 0.05$).

Table 10: 2-WAY ANOVA Test (Dependent Variable: Delay)

| Source | SS | df | Mean Square | F | Sigma (2 tailed) |
|---|---|---|---|---|---|
| Treatment | 2165.680 | 1 | 2165.680 | 5.936 | .016 |
| Primary Decision Maker | 928.304 | 1 | 928.304 | 2.544 | .113 |
| Treatment * Primary Decision Maker | 78.722 | 1 | 78.722 | .216 | .643 |
| Error | 54360.365 | 149 | 364.835 | | |
| Corrected Total | 58336.876 | 152 | | | |

Note: Primary Decision Maker is abbreviated as PDM.

### 3.4.4 Effect of Behavioural Treatment

The Treatment (providing information on loss due to inaction) has a high and statistically significant impact ($p = 0.006$) on intended delay in upgrade of appliances. This proves our hypothesis that *"Framing the monetary cost of delay to replace an inefficient refrigerator, in the present time, would expedite the replacement of refrigerator for a habitual procrastinator."* The null hypothesis can be rejected.

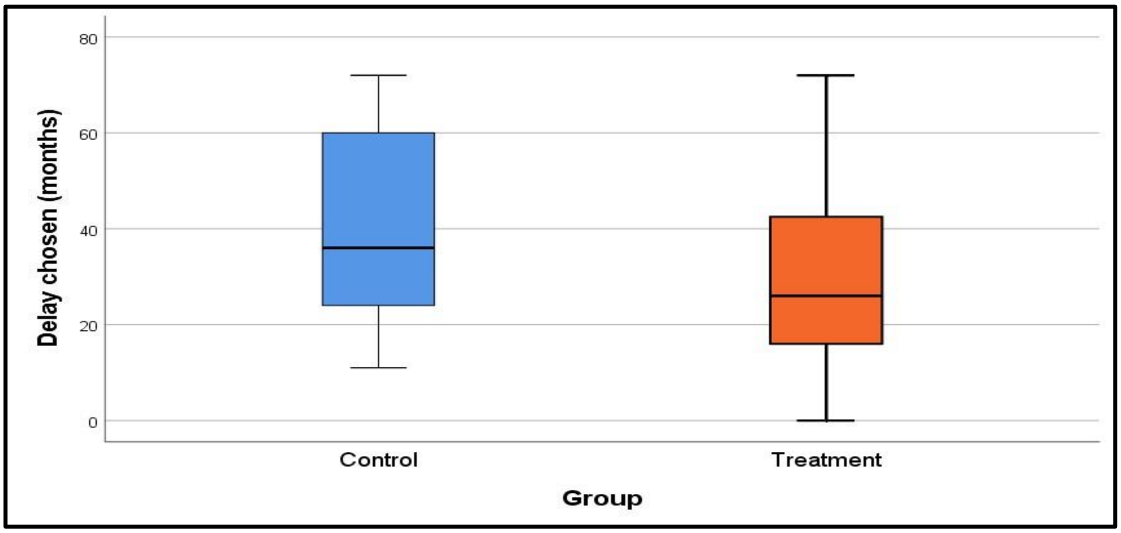


Figure 9: Effect of behavioural treatment on delay

Table 11: Independent samples T-Test for Control and Treatment groups

| | Mean Diff. in Delay | Std. Error Diff | t | df | Sig. (2 tailed) |
|---|---|---|---|---|---|
| Equal variances assumed | 8.610 | 3.103 | 2.774 | 151 | .006 |
| Equal variances not assumed | 8.610 | 3.119 | 2.760 | 145.040 | .007 |

### 3.4.5 Intertemporal choice and the effect of behavioural treatment

Decisions that have consequences in multiple time periods are often called intertemporal choices. The neoclassical view of economics assumes that consumers discount the future at a constant rate — with the discount factor usually represented mathematically as $1/(1 + r)^t$ where r is constant discount rate and t is the length of wait time. As per this classical discounting, the amount a future reward depends on the length of the wait time, and the discount rate which remains constant irrespective of the wait time. However, a large body of evidence from experimental psychology suggests that people (and animals) often express preferences such that rewards with shorter wait times have greater discount rates than those with longer wait times (Ainslie & Herrnstein, 1981; Green, Fristoe, & Myerson, 1994; Kris N. Kirby & R.J. Herrnstein, 1995). For instance, most people prefer $100 now to $110 tomorrow, but very few people prefer $100 in 30 days to $110 in 31 days. Such *preference reversal* of the same decision maker for increasing wait periods can be described by hyperbolic functions (Laibson, 1997). And this oft-observed tendency of consumers to be highly impatient about immediate costs and benefits, with gradual tapering of impatience in the distant future is termed as *Hyperbolic discounting* (Herrnstein, 1961) .

A special aspect of hyperbolic discounting is that the over sensitivity to the immediate costs leads to procrastination of the investment decision when the benefits are expected only in the future. This is particularly relevant and more pronounced in situations such as in the purchase or upgrade of energy-using products or retrofitting of homes and buildings. The hyperbolic discounting model (Mazur, 1987) in which small delays to costs or benefits leads to rapid drop in value initially, while further delays has moderate impacts has been found in literature to descriptively model the consumer discounting better than exponential model (Samuelson, 1937). Decision theory based the hyperbolic discount model can explain the decreasing impatience oft-observed in human (and animal) decisions on intertemporal choice.

Previous studies on the implicit discount rates observed in consumers' purchase decisions came up with a wide range of rates for various energy appliances and efficiency upgrades. Hausman (1979) estimated discount rates of 24.1% to 26.4% in the trade-off between capital costs and operating costs in the purchase of air conditioners. The discount rate in the study varied with remarkably with income: from 39% for the $10,000 income category to 8.9% for the $35,000 category. In a subsequent study, Gately (1980) studied the implied discount rates in six comparisons between high-efficiency and low efficiency refrigerators and reported discount rates ranging from 45% to 300%. He noted this as a market failure and suggested remedial policy measures such as energy-cost labelling and efficiency standards. Another study on consumers' choice between standard and energy-efficient refrigerators by Meier and Whittier (1983) revealed implied discount rates of 20% to 120% with a mere 40% of the consumers having real discount rate of less than 35% . This occurred despite the consumers being well informed of the expected energy savings. Almost all the literature studying the implied discount rate from appliance purchase sought salient energy labelling on the appliances to counter poor access to energy use of appliances. However, a crucial fact missed out in roll out of energy and/or cost labelling and setting minimum energy performance standards is that while these might strongly sway a first-time buyer's choice from an inefficient to an efficient appliance, these policy measures might not have the same impact on consumers who need to upgrade from an existing inefficient appliance. Having a zero purchase cost for retaining the status quo could lead to a much longer delay in energy investment decisions.

The simplistic equation adopted in this study (Green et al., 1994) to estimate the implied hyperbolic discount rate from the chosen delay in refrigerator upgrade is given by V=A / (1+rt), where V is the present value, A is the future amount (cost or saving), t is the delay (in years), and r is the discount rate(Green et al., 1994). The net present value of the refrigerator upgrade is calculated by

*NPV = ∑ {Yearly savings / (1+rt)} - Initial Investment / (1+rt)*

For an investment decision to be at least non-loss making, the total costs must equal total benefits.

*Initial Investment / (1+rt) = ∑ {Yearly savings / (1+rt)}*

The implied hyperbolic discount rate 'r', based on this study, for the consumer decision to upgrade to an efficient refrigerator in year 't' is plotted in Figure 10**Error! Reference source not found.**. For instance, if the consumer chooses to upgrade after 12 months (i.e. purchase by the end of year 1, and benefit from operational cost savings from the start of year 2), substituting the values for initial investment (=749) and t (=1) in the left hand side and yearly savings (149.58) and t (=2, 3, 4, until 10 years lifetime of refrigerator) in the right hand side summation and solving the equation for r, gives an implied discount rate of 27.45%.

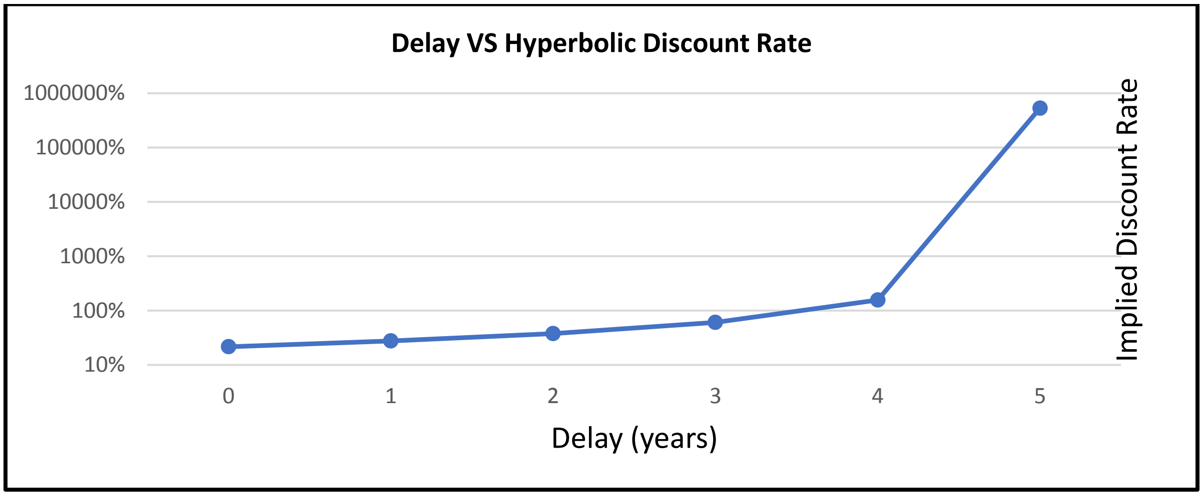


Figure 10: Implied hyperbolic discount rate for delay in appliance upgrade

All the consumers in this study were informed about the average purchase costs and the annual savings that could be obtained in a hypothetical case of a refrigerator upgrade. The delay chosen by the consumer conveyed their sensitivity to the costs in the immediate present and revealed their discounting of the future costs and savings. Although it is not realistic to claim that a single number obtained from our sample is representative of the entire Singapore population, it is fair to assume that the delay chosen shows the size of "efficiency gap" in their failure to make economically rational investments in energy efficiency. The mean discount rate of 75.72% obtained for the control group was within the range estimated by Gately (1980) and Meier and Whittier (1983) indicated before. On the other hand, the treatment group, who were additionally informed of the "cost of inaction" had a much lesser discount rate of 50.19%.

Table 12: Effect of treatment on consumers' discount rate

| | **Initial cost of Upgrade** | **Annual Savings** | **Appliance Lifetime*** | **N** | **Mean Delay in upgrade (months)** | **Hyperbolic discount rate** |
|---|---|---|---|---|---|---|
| **Control** | $749 | $149.58 | 10 years | 73 | 39.7 | 75.72 % |
| **Treatment** | | | | 80 | 31.1 | 50.19 & |
| **Effect of Treatment** | | | | | -8.6 | -25.53 % |

*Technical assumptions include a lifetime of 10 years and a constant electricity price of $0.27/kWh

The inordinately high delay and the (implicit) high discount rate chosen by the consumers despite their awareness of the energy labelling calls to question the efficacy of the 'green tick' labelling alone in persuading a consumer towards appliance upgrade. Despite being aware of future energy savings, if people are consciously over-weighing the present, then the mere display of annual savings might have little impact on investment decisions. Rather, as shown from the results, highlighting the cost of inaction and framing it in the present time seems to have stronger impact in expediting the appliance upgrade. Lesser educated consumers, who seem to be more present-biased (see Section 3.4.3) and delaying appliance upgrades could benefit the most from such treatment.

## 3.5 Policy Implications

Energy labels such as "green ticks" on household appliances can inform the consumers about a product's energy consumption relative to other products in the same class and enable them to make informed choices while making a purchase. Therefore, governments in several countries are actively pursuing stringent policy measures and voluntary programs in the anticipation of large reductions in national energy and carbon emissions. However, key presumptions in these policies is that the consumer arrives at the point of purchase whenever a new appliance needs to be purchased or an old one needs to be replaced. While rising incomes, increased aspirations and affordability of appliances drive new consumers to the purchase point, the crucial question of what drives consumers to visit the purchase point and replace an existing appliance remains less obvious. In other words, what could bring an old horse to the water point, before you could persuade it to drink?

The rapid enhancements in energy efficiency and performance standards of appliances could justify that several old and inefficient appliances can be replaced with net benefits to both the consumer and the planet. However, if the appliance is still operational, there is a possibility that the appliance can be retained in use, far beyond its intended lifetime. Research on the lifetime of appliances in a few developed countries (Lutz, Hopkins, Letschert, Franco, & Sturges, 2012; Young, 2008) corroborates this view that appliances such as room air conditioners, refrigerators and freezers are being kept in active use for much longer than anticipated. On the contrary, studies on appliance lifetime in developing and middle- income countries suggest a shorter lifetime of appliances (Cravioto, Yasunaga, & Yamasue, 2017). The lifetime of of appliances such as ACs, Refrigerators and Washing machines were found to decrease with increase in income up to a threshold point, beyond which the lifetimes rose again with increase in per-capita income. Consumers' age too seems to play a role, with younger households seemingly having more frequent appliance upgrades (Hennies & Stamminger, 2016). Energy efficiency policies seem to have a lower impact for appliance upgrades in countries with higher incomes and more elderly people.

In this study, mere awareness of energy labels (green ticks) did not seem to have any impact in consumers' intended delay for appliance upgrade. However, energy efficiency policies have relied on energy labels and information provision to consumers as their primary strategy for engaging with consumers. This failure of energy labels alone to invoke consumer interest for appliance upgrade is a serious problem, particularly in developed countries, where most households already have several old appliances that are possibly functioning inefficiently, much beyond their expected lifetime.

Another drawback of current energy policies is that by treating all consumers equally, differences between individual capabilities are often overlooked. Consumers who could not make rational choices, even after the provision of technical and cost-benefit information often need better interventions for behaviour change. Highlighting the "cost of inaction" is one such intervention that the policy makers could utilize for persuading the laggards towards faster energy efficiency upgrades and retrofits.

## 3.6 Discussion

Although the detrimental effects of procrastination as an irrational delay is increasingly being recognized as a critical barrier for addressing urgent environmental problems, understanding and treating procrastination remains a challenging task. This study attempts to examine if residential consumers in Singapore delay upgrading their inefficient refrigerators due to severe procrastination trait. We measured consumers' procrastination using self-reported scores. The relationship between self-reported procrastination score and the delay chosen for appliance upgrade exhibits a slight positive correlation, albeit being statistically insignificant. The null hypothesis is therefore retained. The various demographic and contextual factors that could have influenced procrastination were analysed.

Consumers with higher education levels chose to have a lesser delay in upgrade. This proves that education has a role in consumers energy efficiency decisions and the individual discount rates they apply in taking decisions. Also, the role of the individual as the primary decision maker in the household is found to influence the chosen delay. Individuals with a greater control in financial decision making made better decisions for energy efficiency. In contrast to previous studies found in literature, we could not find a significant relationship between procrastination and other demographic factors such as age, income or gender.

Providing information on financial loss due to inaction has a high and statistically significant impact on intended delay in upgrade of appliances. This proves the second of the proposed hypotheses and shows that consumers' inordinate delay in upgrading to efficient appliances can be treated with behavioural interventions.

## 3.7 Limitations of the study

This study is based on online surveys of 168 residential consumers in Singapore. Both the procrastination scores and delay in purchase are derived from self-reported data. Given the hypothetical nature of the questions, it is more likely than not that at least a fraction of respondents could be influenced by the social and cultural norms and responded with answers that are "socially acceptable". The actual procrastination could in fact be much higher or lower than the self-reported one. Secondly, only the "intended" delay in upgrading the refrigerators was measured. But intention is merely a prerequisite for action and the actual purchase action is influenced by many other contextual factors such as break-down of an appliance, availability of finance or the seasonal discounts offered by appliance vendors. Nevertheless, this study reveals a few interesting perspectives on behavioural and contextual factors that could potentially influence consumers' decision in upgrading to more energy-efficient appliances.

# Chapter 4: A behavioural strategy for decarbonizing the building sector: A multi-stakeholder approach in the context of a developing country

## Chapter Abstract

The building sector has overcome several formidable technical and economic barriers in recent years, yet the adoption of energy-efficient building practices remains inadequate in most developing countries. With increased urbanization and higher standard of living, building-related emissions are expected to rise dramatically in emerging economies such as China and India. This chapter provides an assessment of the behavioural biases among the various stakeholders and the structural barriers in the Indian construction sector, for the uptake of energy-efficient buildings. With a specific focus on India, this chapter examines the sociological and behavioural dimensions of decarbonizing the building sector, treating the sector as a collection of key actors working towards individual interests. A multi-stakeholder behavior change strategy is proposed with the application of behavioural interventions and Information and Communication Technologies (ICT). The likely economic impact of such a cross-sectoral strategy and the policy implications are discussed.

## 4.1 Introduction

Buildings are responsible for approximately 32 % of global final energy use worldwide and 51% of global electricity consumption. Studies by the IPCC (2014) suggest that during the past four decades, indirect CO2 emissions from electricity use have quintupled in residential buildings and quadrupled in commercial buildings . The heating and cooling of buildings alone is responsible for 56% of this energy consumed. With increased incomes and rising comfort levels in developing countries the demand for air-conditioning and appliances is expected to lead to higher energy consumption. Rapid urbanization and population growth in these countries will further exacerbate demand for energy as the need for residential and commercial space shoots up in the next few decades.

The building sector has overcome several formidable technical and economic barriers in recent years, yet the adoption of energy-efficient building practices remains inadequate in most developing countries. Despite the obvious advantages and the economic incentive in applying low-carbon practices and technologies in buildings, strong barriers such as information deficit, access to finance, high discount rates and sectoral inertia hinder their market uptake. In addition, the actual design and construction of buildings itself is influenced by several social, cultural, behavioural and regulatory considerations that are specific to the region in which the sector operates. The technological progress achieved in building design and construction methods can spur large-scale energy transition in the building sector only when the social, behavioural and structural barriers too are adequately addressed.

Encouraging behavioural and lifestyle changes is increasingly being recognized globally as a crucial enabler for the uptake of improved efficiency in the building sector (Lucon O. et al., 2014; Urge-Vorsatz et al., 2012; WBCSD, 2007). Although the appetite for energy-efficient construction and low-carbon lifestyles is influenced by the biases at the individual level, the quantum of behavior change that can be brought about is bounded by the institutions and the existing practices among the diverse stakeholders in the construction ecosystem. An individual can change only as much his surroundings and social context permits him to. Much of the research and discussions on sustainable behavior change until now have focused on individuals and sectoral behavioural change is still an unexplored topic. But for the rapid decarbonizing of the building sector it is imperative to consider a sector-wise strategy that involves all the key stakeholders that could potentially impact the change. Such a strategy should understand the barriers both at the individual and sectoral level, suggest goals and actions for each stakeholder that when implemented simultaneously could enable a systemic change.

## 4.2 Climate change and the built environment

### 4.2.1 The impact of the building sector on climate change

The building and construction sector is responsible for at least 18% of global greenhouse gas (GHG) emissions in 2010 (IPCC, 2014) .  It is also the largest consumer of resources in the world, which in turn has substantive implications on the energy use and GHG emissions (Krausmann et al., 2009). This consumption is expected to increase in the coming years because of increasing population, rapid changes in lifestyles and increased appliance usage. This problem could be further exacerbated due to global warming, particularly in warmer countries, when cooling demand in buildings increases exponentially with rising temperatures. However, owing to its large size and its extensive supply chains, the sector offers the maximum opportunity with the least cost for GHG abatement among the major sectors requiring transformation (Figure 11). Given that buildings have long economic lifespans as compared to other energy-consuming infrastructure (IEA, 2013), designing and constructing them for minimal energy impact has a very high potential for climate change mitigation. For developing nations in Asia, Africa and Latin America, where most of the buildings required by 2030 are yet to be built, building them efficiently the first time efficiently offers huge economic and environmental opportunities.

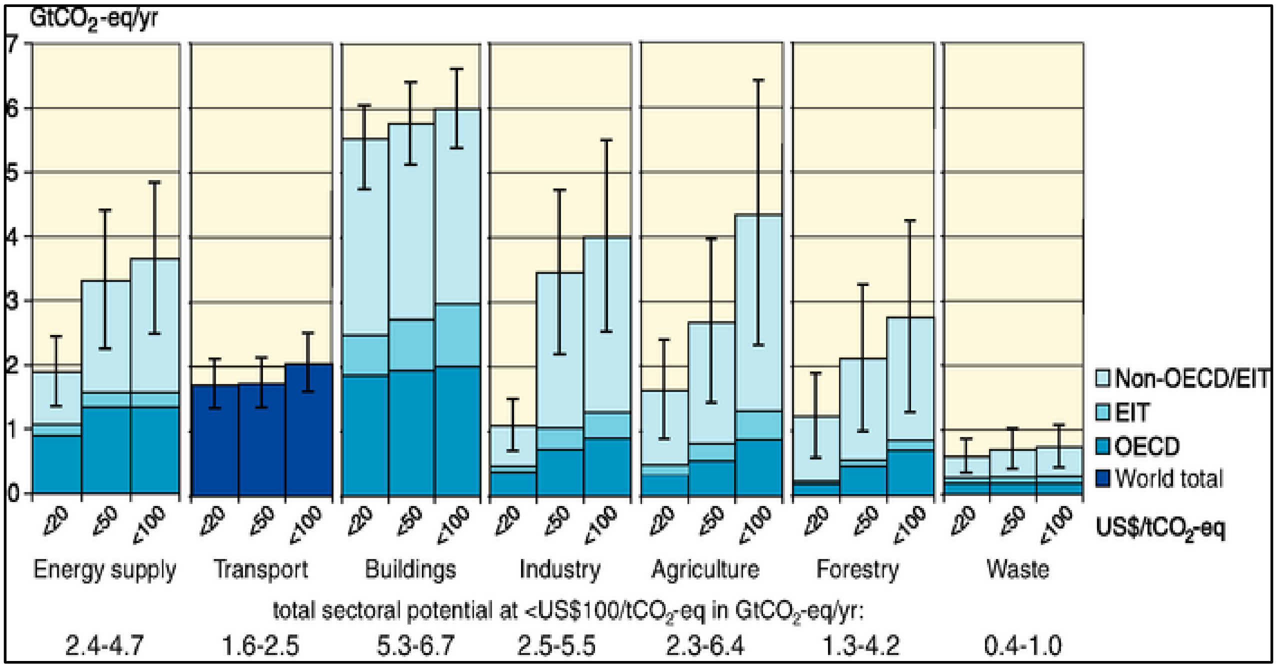


Figure 11: Economic mitigation potentials by sector in 2030 estimated from bottom-up studies
**Source**: IPCC Fourth Assessment Report: Climate Change 2007.

The lifecycle of a building has four phases: construction, operation & maintenance, renovation and demolition or disposal. In terms of a lifecycle energy perspective, there are primarily two categories of energy use in buildings:

- Embodied Energy (Initial and Recurring)
- Operational & Maintenance Energy

The share of each component varies to a great extent, depending on the types of material used in construction and quantum of space conditioning used during the operation phase. Considerable advances have been made in the past few decades on increasing the performance of buildings during their operational phase. For instance, electricity use in buildings has been declining steadily due to improved energy efficiency measures, increased energy prices and the gradual uptake of household renewable energy systems. With an emphasis mainly on energy efficiency during the operational phase of the building lifecycle, energy use in the other phases has either been neglected or considered less important until recently. However, recent research persuades more attention towards the other phases as well (Praseeda, Reddy, & Mani, 2016;

Thormark, 2002). Embodied energy accounts for a considerable part of energy during a building's lifecycle, particularly in the much touted "low-energy" houses or "green buildings" which fail to consider the energy required to extract and transport the construction materials.

#### 4.2.1.1 Embodied Energy

The embodied energy of a building is the sum of all the non-human energy required to extract the raw materials from nature, to make building products and to transport them to construction site. The embodied of any building material is the sum of the direct and indirect components of energy used. The indirect component is the energy required for the extraction and transportation of raw materials. This varies greatly depending on the source of extraction. For instance, if the raw material is directly from nature (say for burnt clay bricks) the indirect component is the non-human energy spent on extracting clay. The direct energy component in this instance is the energy spent in the production of the brick and the energy for transporting it to the construction site. Typical embodied energy computed for basic building materials is given below (Table 13). The majority of embodied energy is consumed during the construction of the building and a small part is consumed during renovations, if any.

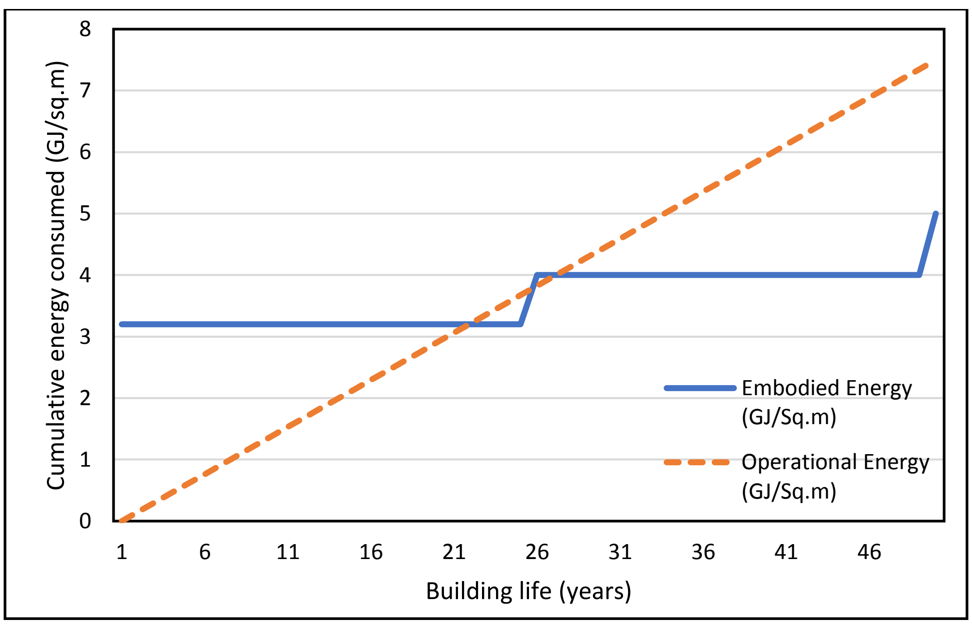


Figure 12: Embodied and Operational energy consumption pattern in a typical building

**Source**: Adopted from (Praseeda, 2018)

Table 13: Embodied energy of few basic building materials

| Type of material | Embodied energy (MJ/kg) |
|---|---|
| Cement | 5.85 |
| Lime | 5.63 |
| Lime-Pozzolana | 2.33 |
| Steel | 42.0 |
| Aluminum | 236.8 |
| Glass | 25.8 |

**Source**: (Venkatarama Reddy & Jagadish, 2003)

#### 4.2.1.2 Operational Energy

Operational energy of a building is the total energy consumed for the functioning and maintenance of facilities inside the building. The energy consumed is mainly used for

- Lighting
- Space conditioning
- Water heating
- Mechanical ventilation
- Running electrical appliances

Unlike the embodied energy, operational energy depends on the lifetime of the building, and has a linear relationship with the useful life of the building (Figure 12). Operational energy usage depends on the function of the building, the climatic conditions in which it performs and the type of appliances required to provide lighting and thermal comfort to the occupants. For instance, buildings in cold and composite climate use a large amount of energy for running air-conditioners for heating and cooling respectively. Dwellings in warm-humid need cooling or active ventilation only for a few months in a year, while those in moderate climate do not require any mechanical space conditioning systems. Typical operational energy usage per unit floor area of a residential building, for four generic climate zones with appliance usage primarily for lighting and space-conditioning is compared in Table 14.

Table 14: Annual operational energy in urban residential dwellings for different climatic conditions

| Climate zone | Operational energy (GJ/m$^2$/year) |
|---|---|
| Composite climate | 0.04 – 0.22 |
| Warm-humid climate | 0.03 – 0.04 |
| Moderate climate | 0.01 |
| Cold climate | 0.06 |

**Source**: (Praseeda et al., 2016)

The lifecycle energy (LCE) consumption of a building includes both the embodied energy and the operational energy. While operational energy is consumed throughout the life of the building, most of the embodied energy at initial construction and a minor part during recurring renovations. Energy required at the end-of-life of a building for demolition and disposal is barely 1% of the lifecycle energy (Praseeda et al., 2016) and is therefore generally not considered for the calculation of LCE of a building.

### 4.2.2 Opportunities for saving energy and mitigating climate change

Operational energy forms the bulk of the energy consumed during a building's life. Multiple options exist to control and minimize the operational energy consumption of buildings. The primary and the most important of them is to plan and design the building to have good natural lighting, avoid excessive solar heat gain on the building envelope and to have systems that drive natural ventilation in to the building. Where the design or climatic conditions do not permit to achieve all these optimal conditions, usage of energy-efficient lighting, space-conditioning can help achieve these conditions. Adopting low-energy and building-integrated renewables into the building system can offset at least part of the energy demand. Additional measures to reduce include adopting:

- Occupancy-based lighting controls
- Passive air-conditioning systems
- Use fuels having lower carbon intensity
- Use of energy recovery techniques
- Measurement and control through Building Management systems
- Periodic maintenance of the systems
- Building codes and certifications that promote energy efficiency

Saving of embodied energy of the buildings has received scant attention until now. However, they do form a non-trivial part of total emissions. A majority of the materials used in modern construction use energy-intensive materials such as steel, cement, glass, aluminum (see Table 13) which have a huge contribution to the Life Cycle Energy of a building and to larger national emissions budget. Acknowledging and reducing these emissions is paramount to making a building truly zero-carbon (Thormark, 2002). Some of the alternative low energy materials include products made from waste, recycled materials and biomass materials such as bamboo, stabilized soil blocks, rammed earth structures, unreinforced masonry and filler slab roofs (Venkatarama Reddy & Jagadish, 2003). Bringing down the embodied energy of buildings entails:

- Minimizing the use of high energy materials
- Utilizing locally-available materials
- Using products and materials that have high recycled content
- Respecting local diversity and adopting vernacular architecture in building practices
- Prolonging the usage life of materials through periodic maintenance
- Advanced design that permits easy disassembly and reuse of materials
- Including embodied energy as important criteria in building codes and certifications

The IEA (2013) estimates that in the absence of action to improve building energy efficiency, the sector's global energy demand is expected to increase by 50% by 2050. But with a concentrated effort by deploying the best of available technologies, it is possible to restrict to only a 10% increase in energy use without changing comfort levels or reducing appliance usage. This number could possibly be reduced even further, with the choice of low energy materials and with recycling and reuse of existing materials. Without immediate corrective actions we risk locking in high carbon emissions in buildings for many decades to come.

## 4.3 The urgent challenge of the building sector in India

India is currently the third largest energy consumer in the world (IEA, 2013). Being the world's fastest growing major economy, managing this country's carbon emissions plays an important role in the world's ability to limit global temperatures to well within 2$^{o}$C. The country with an estimated population of 1.3 billion people in 2016 is rapidly urbanizing, with urban population expected to eventually overcome rural population by 2050. Energy consumption in buildings, which currently accounts for roughly 40% of country's final energy consumption and is expected to rise further in the coming decades. The International Energy Agency (IEA) (2011) estimates the global number of households to grow by 67% and the floor area of commercial and institutional buildings by almost 195% by 2050 from a 2011 baseline. Models developed by the Centre for Climate Change and Sustainable Energy Policy for Global Buildings Performance Network (Urge-Vorsatz et al., 2012) estimates a 94% increase in floor area for residential buildings and an 88% increase for commercial buildings by 2050 from 2010 baseline. In the absence of interventions to reduce energy consumption, the energy demand is expected to follow the trend of increase in the building area. Even in a "moderate scenario" where all of today's policy trends and ambitions are implemented, global building energy use will still increase by about a half of 2005 levels, primarily driven by economic development and the construction boom in emerging economies such as China and India. If building site energy consumption in China and India grows to current US levels, China's and India's consumption will be respectively about four and seven times greater than what they are today.

India's building sector is currently witnessing an unprecedented growth, with the floor area projected to increase by 400% between 2012 to 2050 (GBPN, 2014). It is estimated that there is already a shortage of at least 18.78 million residential units in urban areas and 43.67 million units in rural areas, which is expected to generate large investments both from the government and the private sector. With rising incomes, increased appliance usage and an escalating demand for air conditioning, electricity use in buildings is expected to increase by an alarming 500%-800% during the same period, in the absence of interventions (Figure 13). A vast proportion of this growth in energy consumption is expected to occur in residential buildings. Considering that buildings have long "lock-in" period of 40-60 years, including ambitious energy efficiency measures at the design and construction stages is the most economical and effective way to restrict emissions. Given that 70 percent of India's buildings are yet to be built (Sankhe et al., 2010), there is an urgent need to drive the building sector towards resource-efficient building practices.

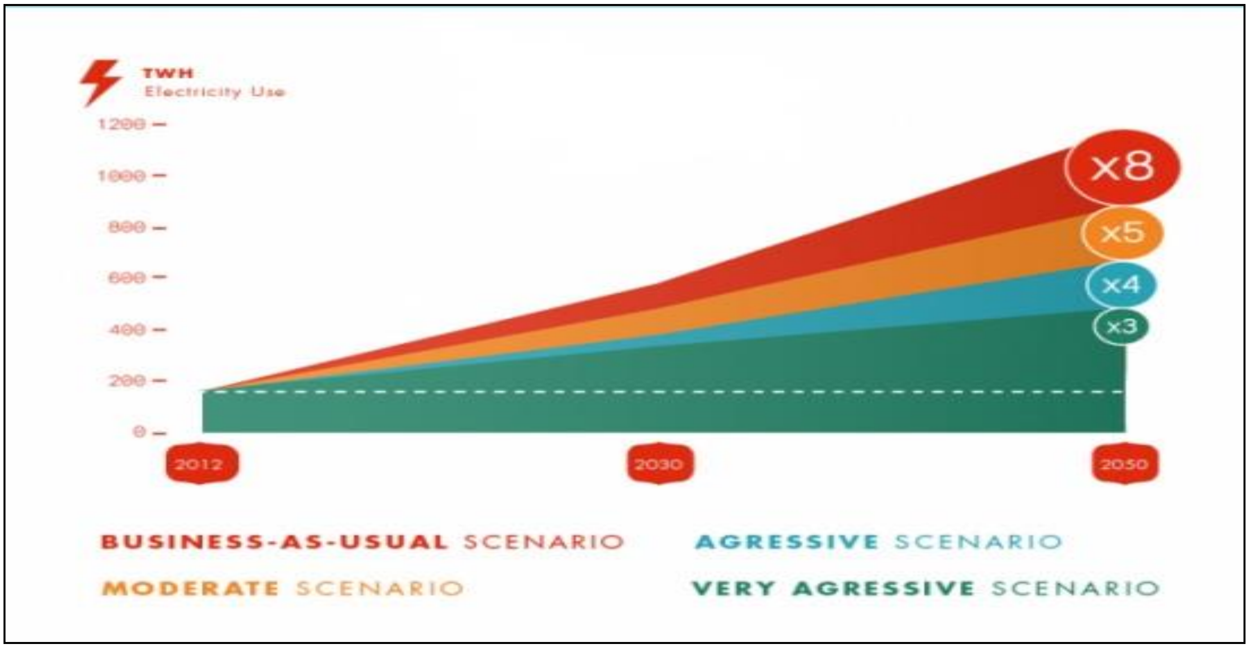


Figure 13: Electricity demand projections for buildings in India

**Source**: (GBPN, 2014) India, Building a Sustainable Energy Future For All Homes.

### 4.3.1 Resource, Energy and Carbon footprint of the sector

The building and construction sector in India contributes to about 8% of the country's GDP and employs over 45 million people. Construction in India is expected to soon become the third largest sector in the world. However, it is by nature the most resource-intensive and environmentally destructive industry. The industry consumes 30% of the nation's electricity and generates 23.6% of the carbon emissions (Development Alternatives & GIZ, 2015). It is also the largest user of natural resources in the country, consuming up to 2.8 billion tons of raw materials, most of them from non-renewable natural resources.

Almost all the raw materials used in a building or construction end up as debris by the end of its lifetime of 40-60 years (Figure 14). The Centre for Science and Environment in India estimates that the Building sector alone today produces more than 530 million tons of construction and demolition (C&D) debris each year (CSE, n.d.), much higher than previous estimates by the Indian government. Estimates suggest that less than 20% of the C&D waste is currently recycled, with most of it being sent to landfills, or getting dumped in open spaces or illegally being used to fill water bodies for encroachment in space-constrained cities. Reliable data on the quantum of C&D

waste generated is often sketchy, and the Indian government estimates it to be at least 25% of total solid waste generated in urban areas (TIFAC, 2011). While accurate data on the fractions of materials that are currently reused or recycled are non-existent, it could be derived, to an extent, from the components of the C & D waste sent to authorized landfills (Figure 15).

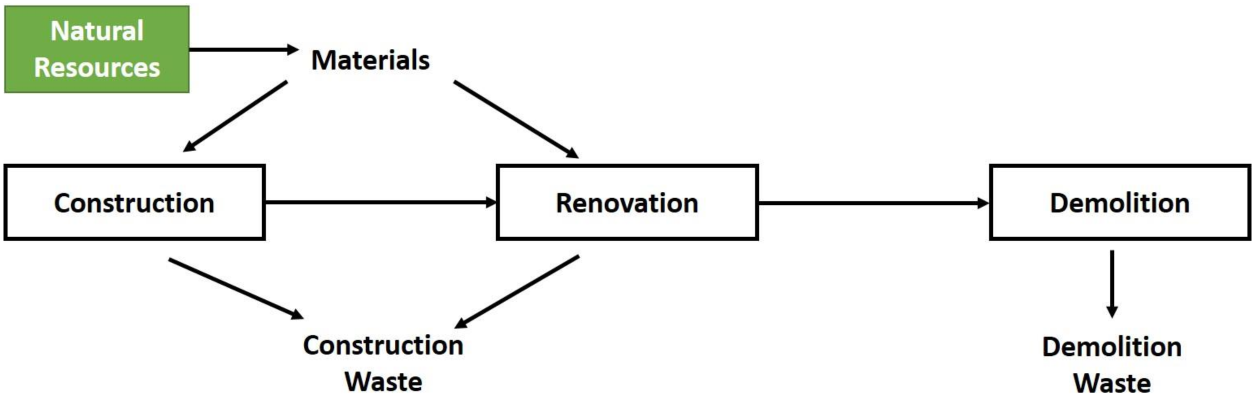


Figure 14: Material flow diagram in a linear flow

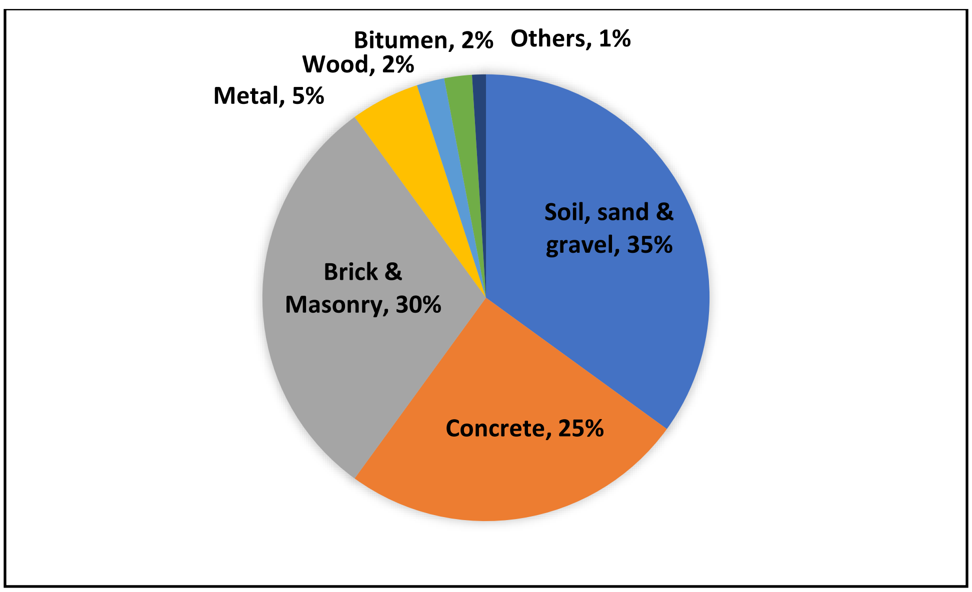


Figure 15: Typical composition of C&D waste in India
Source: (TIFAC, 2011)

Rapid urbanization is changing the landscape of India and causing a rapid increase in new construction along with the demolition of shorter buildings to make way for taller ones. This construction boom has led to enormous demand on construction materials derived from natural resources. However, such critical resources used by the building sector are finite and take a long time to replenish. Supply shortages for products such as natural river sand and aggregates has led to a budding demand for more energy-intensive products such as manufactured sand (m-sand). Unless immediate steps are taken to reduce the resources used and to recycle and reuse construction waste, the environmental cost will only aggravate further due to the expected construction boom. Resource decoupling and resource productivity – by using lesser material for the same economic output is an urgent necessity to alleviate the growing scarcity of natural resources. Doing this the right way provides an enormous opportunity for decoupling the building sector from environmental degradation. Closing the material flow loop from the current linear flow (Figure 14) to a circular flow where waste is considered as a valuable resource is of utmost necessity.

The operational energy of a building depends on the operational energy intensity of the building and the useful life of the building. Table 14 lists the typical energy intensity of residential buildings in different climate zones. The embodied energy of a building depends on the quantity and energy intensity of materials used in construction. The amount of C&D waste generated is dependent on several factors. Important among them are demographic factors such as population, rate of urbanization, population density and per-Capita GDP. Type of the dwelling, socio-economic characteristics and demolition patterns are other factors that define the quantity of C&D waste generated. Modelling this for the decades until 2100 will give an estimate of the quantum of construction expected, the expected materials required, the embodied energy and thereby the carbon emissions generated from the buildings constructed.

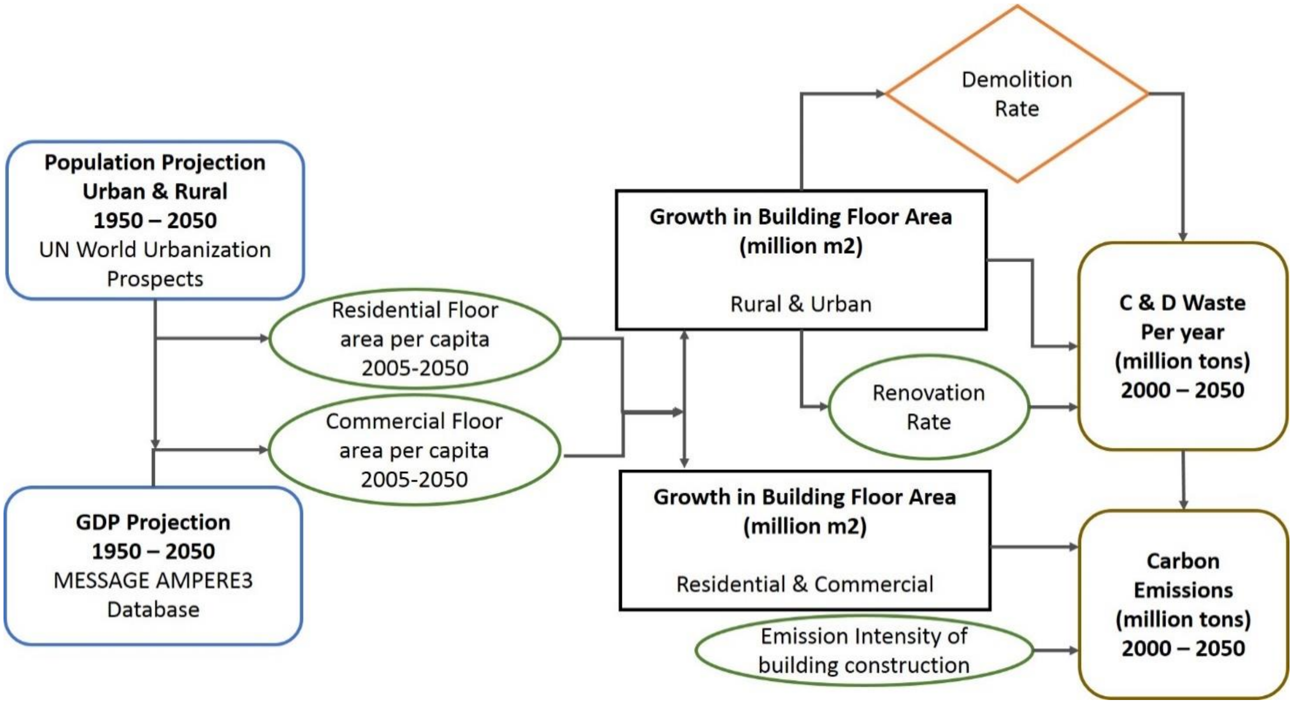


Figure 16: Modeling Carbon emissions from Construction and Demolition of Buildings

**Population and GDP**

The demand for residential building space is expected to be directly proportional to the projected population and the per-capita GDP. The projections for population and urbanization until 2050 are taken from the United Nations World Urbanization Prospects (United Nations, Department of Economic and Social Affairs, Population Division, 2014).

Table 15: Population and Urbanization projections for India

| Population (thousands) | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| **Urban** | 288 365 | 372 902 | 470 726 | 583 038 | 701 358 | 814 399 |
| **Rural** | 753 897 | 832 723 | 882 579 | 893 339 | 864 151 | 805 652 |
| **Total** | 1 042 262 | 1 205 625 | 1 353 305 | 1 476 378 | 1 565 509 | 1 620 051 |

(TIFAC, 2011)

Table 16: GDP and GDP per-capita projections for India

| | 2000 | 2010 | 2020 | 2030 | 2040 | 2050 |
|---|---|---|---|---|---|---|
| **GDP (billion $)** | 606.60 | 1495.40 | 3285.50 | 6699.80 | 11610.00 | 17542.00 |
| **GDP per capita ($)** | 582.00 | 1240.35 | 2427.76 | 4538.00 | 7416.12 | 10828.06 |

Source: (IIASA, n.d.)

Projections for the per-capita GDP are derived from the MESSAGE 3 database from the International Institute for Applied System Analysis (IIASA), which is commonly used for Integrated Assessment Modelling for the energy sector. The Global Buildings Performance Network (2014) has estimated the total commercial floor area and per-capita residential floor area for 11 regions of the world, for 2005. The per-capita floor area in 2005 for India is calculated for this estimate. We assume that by 2050 per-capita residential floor area will be similar to that of Western Europe. On the other hand, we assume that the commercial floor stops being proportionate beyond 2030 and will rise only partially until it reaches five times the per-capita figures observed in 2005.

**Floor area assumptions for residential and commercial buildings**

Table 17: Assumptions on floor area per-capita

| | Residential Floor area per capita in 2005, m2/cap | | | | Commercial Floor area per capita in 2005, m2/cap |
|---|---|---|---|---|---|
| | Urban Single-family | Urban Multi-family | Informal (slums) | Rural Single-family | |
| South Asia – 2005* | 6.7 | 5.1 | 2 | 8.3 | 1.5836 |
| India (2020) | 16.475 | 10.825 | 2 | 17.675 | 4.1231 |
| India (2030) | 26.25 | 16.55 | 2 | 27.05 | 7.7071 |
| India (2040) | 36.025 | 22.275 | 2 | 36.425 | 7.8125 |
| India (2050) | 45.8 | 28 | 2 | 45.8 | 7.9181 |

*The 2005 figures are adapted from GBPN (2014)

Table 18: Assumptions on percentage of population per type of dwelling

| Dwelling Type | Single Family | Multi-Family | Informal (Slums) | Single Family |
|---|---|---|---|---|
| Urban | 24% | 74% | 2% | |
| Rural | | | | 100% |

**Pattern of Construction and Demolition**

Cities in India are space-constrained and have a penchant for vertical growth, often at the cost of demolishing an older but perfectly functional building. This adds an undue pressure on an already constrained natural environment for additional resources. Frequent demolition and renovation of buildings in urban areas leads to excessive wastage of materials during construction, renovation and buildings. While literature suggests a wide range of optimistic values for expected life of buildings ranging from 40 to 120 years (IEA, 2013), recent estimates from fast-growing Asian countries such as China and Singapore reveal a much lower lifetime of 25-30 years, after which the building is brought down to make way for much taller or "new-design" buildings. We estimate the building floor area projections for a narrow band of expected lifetimes of 30, 40 and 60 years, considered them as "pessimistic", "moderate" and "optimistic" assumptions of building lifetime. We assume that demand of residential buildings will get eventually fulfilled with rising incomes in India. The expected growth in building floor area for rural and urban areas from 2000 to 2050, with "moderate" assumptions, for residential and commercial purposes are shown in Figure 17 and Figure 18.

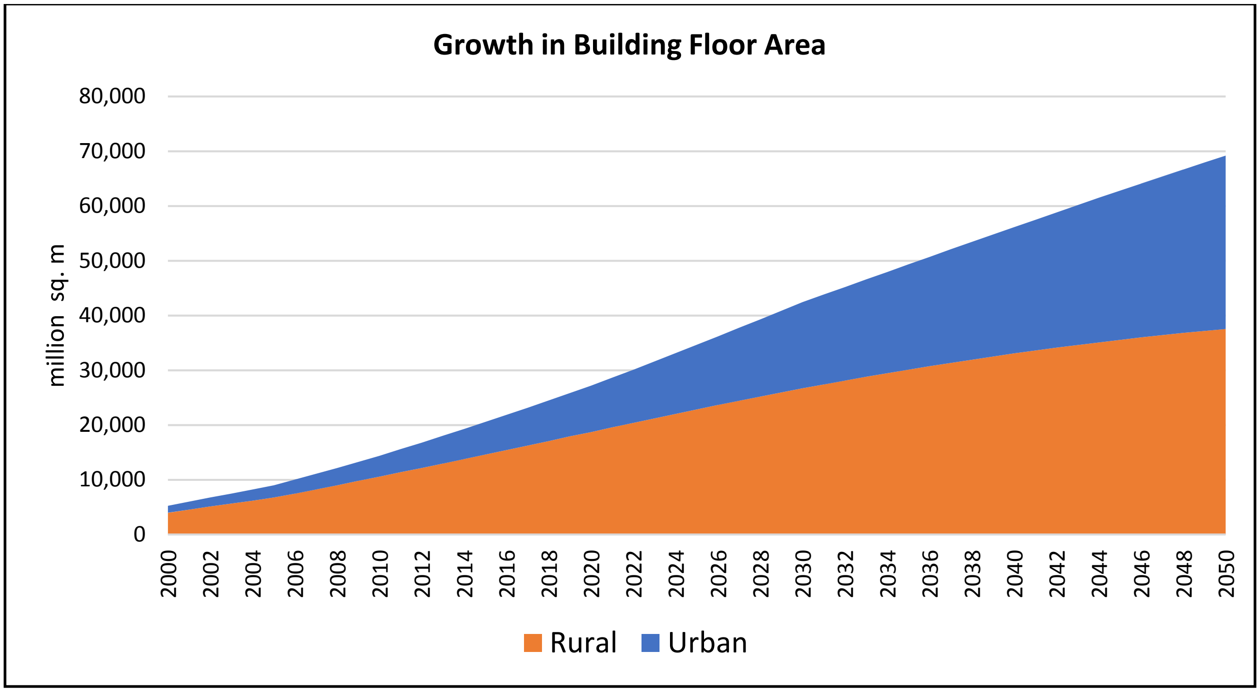


Figure 17: Projected growth in buildings for rural and urban areas in India
Source: Estimates from model developed by the author

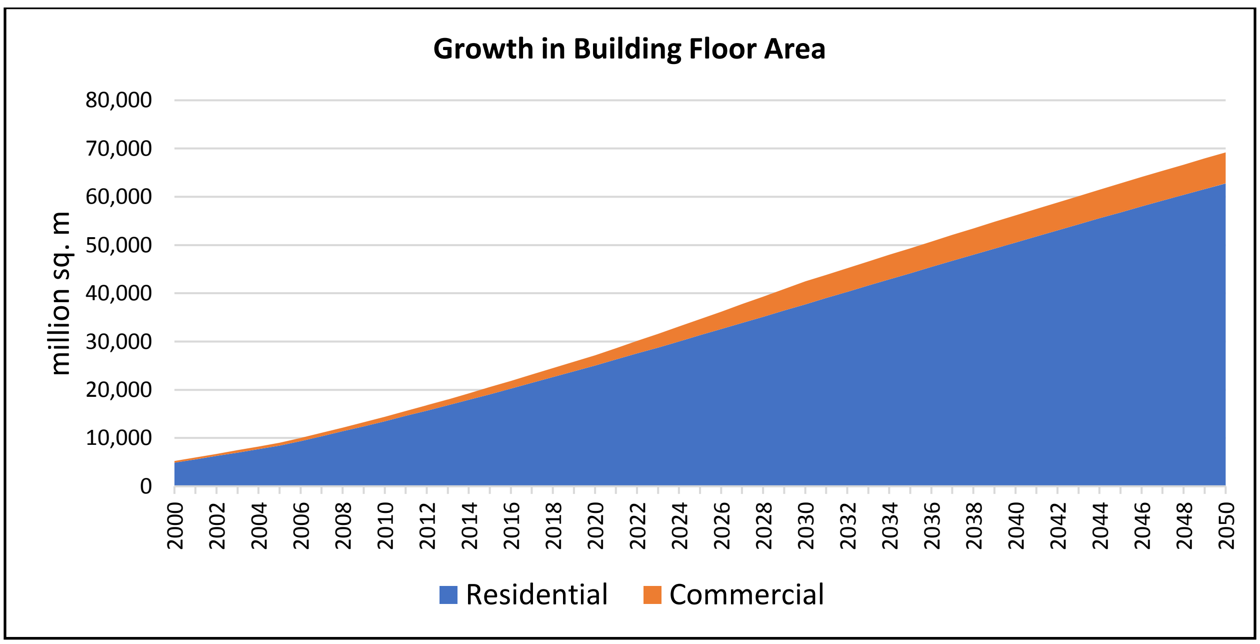


Figure 18: Projected growth in residential and commercial buildings
Source: Estimates from model developed by the author

**Material and Waste intensity of construction and demolition**

The quantity of material used for buildings prior to and post occupation depends on the prevalent construction norms and cultural practices of a region. Studies on the exact quantity of material for each geographical location or city is absent in India. However TIFAC (2011) in their study, gave a reasonable estimate on the quantity of material wasted during the construction, renovation and demolition phases of a building's lifecycle (Table 19). This could be used as proxy to arrive at reasonable estimates of C&D waste generated per year, and the embodied energy utilized by the buildings per year. We assume that 2% of the existing building stock is renovated/repaired each year and 20% of the building materials are either reused or recycled into other useful products after demolition. The estimates of C&D waste generated from 2000 to 2100 are mentioned in Figure 19.

Table 19: C & D waste per unit building floor area in India

| Activity | Waste per $m^2$ of floor area based on TIFAC (2011) | Considered in our model |
|---|---|---|
| **New construction** | 40-60 kg | 50 kg |
| **Renovation** | 40-50 kg | 50 kg |
| **Demolition (Urban areas)** | 300- 500 kg | 500 kg |
| **Demolition (Rural areas)** | 300 kg | 300 kg |

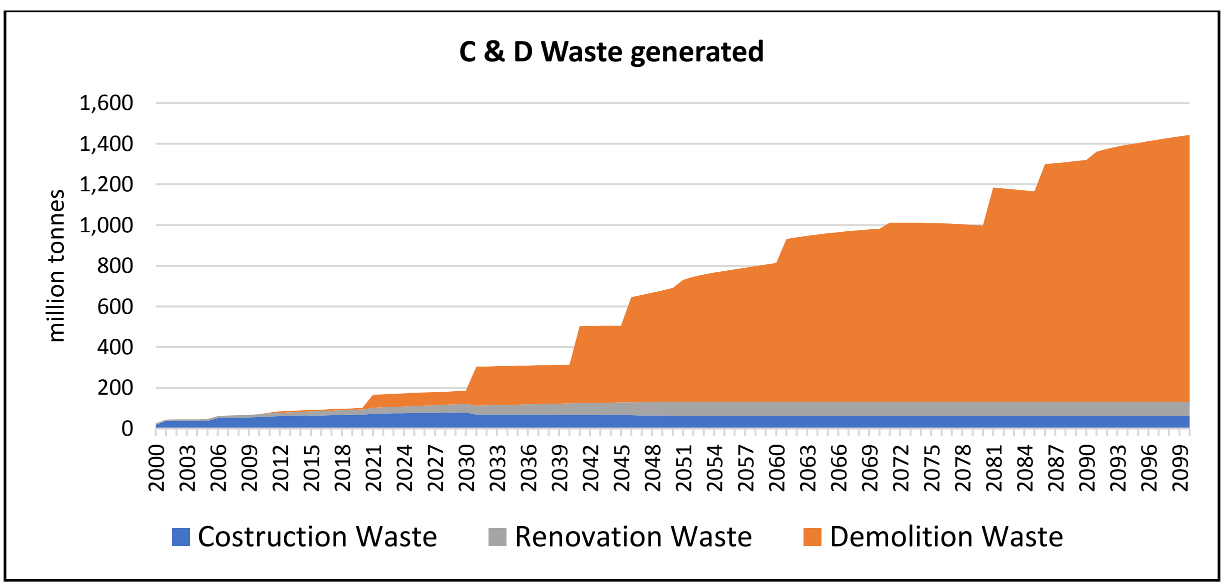


Figure 19: Estimate of Construction and Demolition waste generated for a "moderate" lifetime of buildings

**Energy and Emissions from the sector**

The lifecycle energy (LCE) consumption of a building includes both the embodied energy and the operational energy. Firstly, the embodied energy is estimating the building floor area and multiplying it by an average value of embodied energy intensity for residential buildings. Studies by Praseeda (2018) pegs this value at 2167 MJ/sq.m (See Appendix E). The operational energy estimates are derived by assuming the percent of buildings in each of India's major climate zones based on the geographical area under each zone (See Appendix F) and considering two factors – the average operational energy intensity (Table 14) and the expected lifetime of the buildings. For the sake of simplicity, the share of buildings in each climatic zone and the operational energy consumed per year are assumed to be constant throughout the time period considered.

Table 20: Climate zones in India

| Climate zone | Assumed % of buildings in the climate zone | Household Operational energy used (GJ/m2/year) (Praseeda et al., 2016) | Operational energy used for heating, cooling, hot water (GJ/m2/year) (Ürge-Vorsatz, Cabeza, Serrano, Barreneche, & Petrichenko, 2015) | Considered in our model (GJ/m2/year) |
|---|---|---|---|---|
| Hot-Dry climate | 20% | 0.04 – 0.22 | 0.236 | 0.236 |
| Warm-humid climate | 35% | 0.03 – 0.04 | 0.236 | 0.236 |
| Composite climate | 35% | 0.03 – 0.04 | 0.236 | 0.236 |
| Temperate climate | 5% | 0.01 | 0.236 | 0.01 |
| Cold climate | 5% | 0.06 | 0.236 | 0.06 |

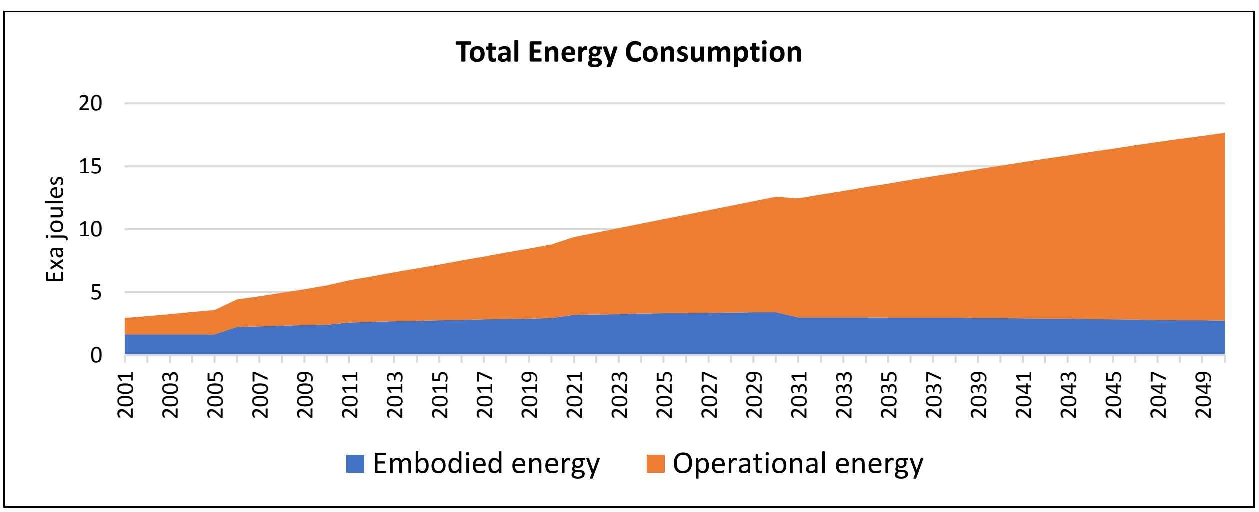


Figure 20: Projections of Total energy consumed by the building sector in India

The estimates of total energy consumption by the building sector (Figure 20) shows that owing to the rapid pace of construction in India, embodied energy consumed by constructing new buildings each year varies between half to one-tenth of total energy consumption during 2001-2050. Targeting the reduction of embodied energy is as important as improving the operational energy performance of buildings if lock-in of enormous amount of energy in the building stock must be avoided. Unfortunately, most of the policies and green-certifications give far lesser importance to embodied energy or is often overlooked while estimating the energy consumption of building sector in the country. Increasing the efficiency of construction practices, reduction of wastage and uptake of less energy-intensive materials must be addressed by policy at the earliest to avoid a dangerous environmental blunder in the making.

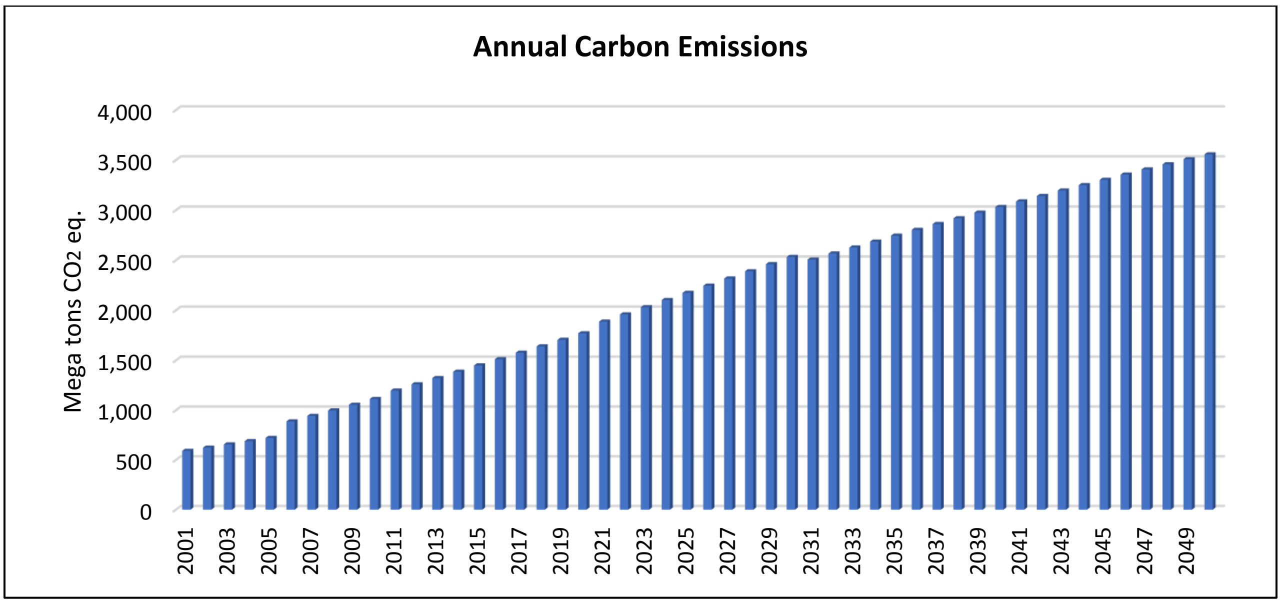


Figure 21: Projections of total carbon emissions from the building sector in India in Business-As-Usual scenario

The emission intensity of energy in 2001 is assumed to be equal to electricity grid emission factors (0.72 kg $CO_2$ per kwh) derived from the AMPHERE 3 MESSAGE Base model (IIASA, n.d.). Grid emission factors are fixed at 2015 levels to reflect the Business-As-Usual case (e.g. no significant energy reduction). Any improvements in the grid is expected to be compensated by extra processing required for converting scarce resources into useful materials for construction. The estimates of carbon emissions thus obtained are shown in Figure 21.

### 4.3.2 Attitudes and Productivity of the Sector

The economic contribution of construction industry is more significant in developing countries as compared with developed ones. Already accounting for 10% of the GDP and employing more than 45 million people, India's building and construction sector is poised to soon become the largest contributor to the country's GDP. With 60% of the population expected to live in cities by 2050 (United Nations, Department of Economic and Social Affairs, Population Division, 2014), the demand for housing and the future for building sector has never been brighter. However, this sector is plagued with excess material wastages, project delays and performance inefficiencies, which if left unchecked can have severe detrimental effects to the economy and the environment. Studies have revealed that many of these wastages and inefficiencies occur primarily due to human factors such as lack of awareness, non-collaborative planning and design, frequent design changes (Agyekum, Ayarkwa, & Adinyira, 2012) and indifferent attitudes of construction participants towards wastage (Yadav, Pandey, & Agarwal, 2017) . These could potentially be corrected with remedial behavioural interventions.

A recent McKinsey report on the sector's productivity (Barbosa et al., 2017) reveals that globally, labour-productivity in the building and construction sector lags far behind the manufacturing sector and is consistently below the economy average during the past two decades. Although this seems to be a global problem, this is much more pronounced in India where the building sector's labour-productivity is abysmally low, and stands at one-tenth of the global average. Cost of labour is the second largest expense in an Indian building and infrastructure project (see Table 21). Over-dependence on manual labour which is abundantly available has led to productivity being unduly affected by human factors including excessive unskilled labour, poor project planning and coordination and frequent revisions to design, thereby leading to excessive project delays and material wastages. Given the construction sector's economic size, any behavioural changes towards marginally higher productivity can have an immense impact both on the economy and the environment. Adopting Behavioural interventions aided by technological solutions can foster a sustainable growth pattern for India and for the world.

Table 21: Cost distribution in a typical building project

| | Materials | Labour | Construction Equipment | Finance | Enabling Expenses | Administration Expenses | Other |
|---|---|---|---|---|---|---|---|
| **Contribution to cost of a building** | 58-60% | 11-13% | 4-5% | 7-8% | 5.5-6.5% | 3.5-4.5% | 5-6% |

Source: (Jain, 2012)

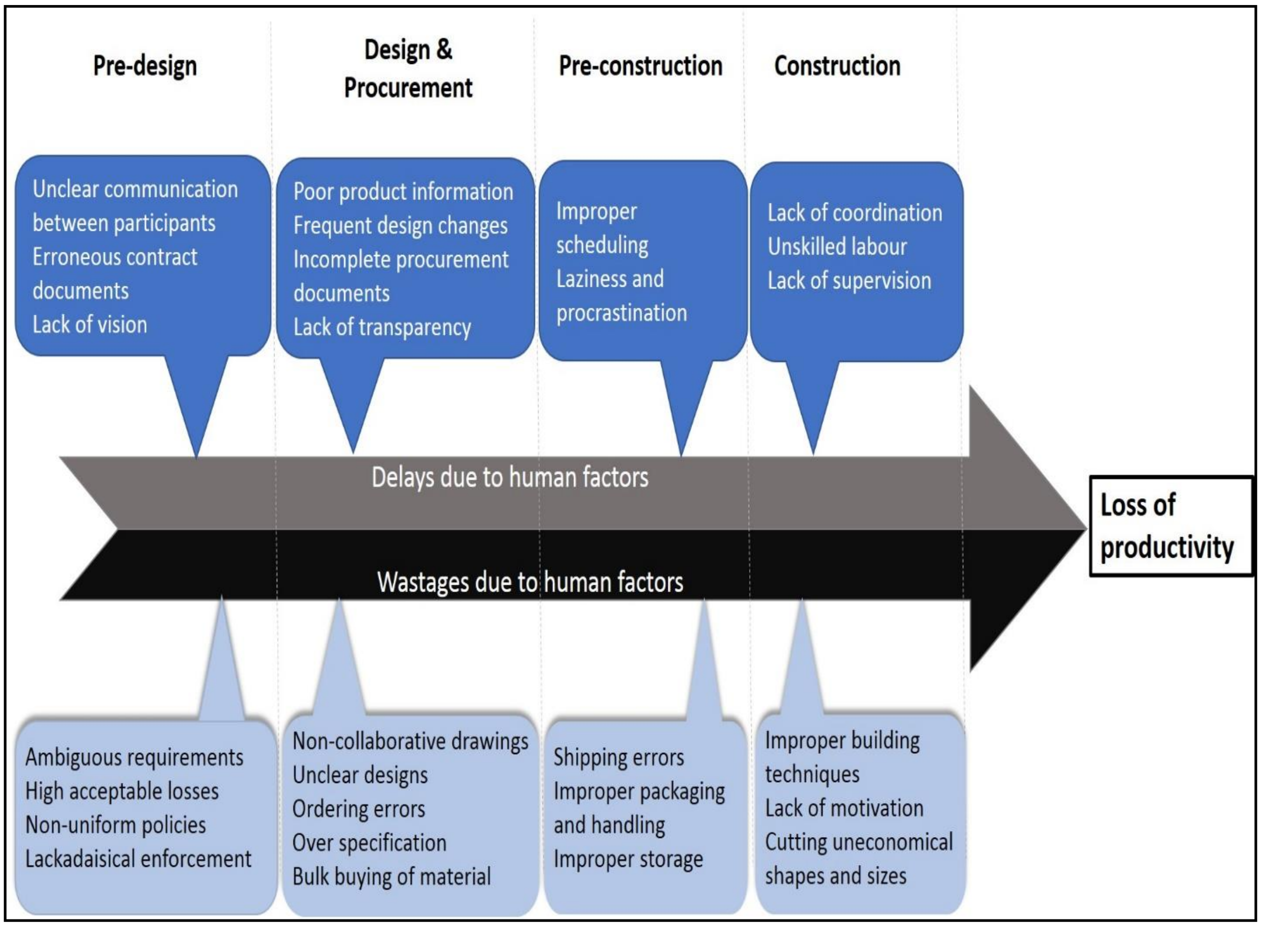


Figure 22: Behavioural causes for low productivity in India's building sector
Source: Stakeholder discussions held by the author

On the bright side, much of the technology required for energy-efficient buildings is readily available and can be quite cost effective, especially when considered over a longer time to realize the benefits. Studies by the IPCC demonstrate that the building sector has the greatest potential to mitigate carbon emissions at the lowest cost (Figure 11). This is particularly relevant in the context of India, where as much as 80% of the operational cost of standard buildings can be saved through integrated design principles in new buildings, often at little or no extra cost.

Our projections for the growth of Indian construction sector shows that at least 60% of the building stock that would be existing in 2050 is yet to be built (Figure 23). Getting the act of constructing these thousands of buildings judiciously avoids a dangerous lock-in of many exajoules of embodied energy and prevents unnecessary consumption of operational energy and capital that could otherwise be utilized for other economic purposes. Hence, there is an urgent need to drive the building sector towards resource-efficient building practices using all possible proven means currently available. Given the un-organized nature of the sector and the intricate dependencies between varied types of participants, a sector-wide strategy that includes every stakeholder in a rapid transformation is a critical necessity. Furthermore, the building sector offers the greatest potential of contributing to meeting other key sustainable development goals including poverty alleviation, energy security, and improved employment. Addressing this pressing challenge in India by addressing the building sector systemically for a large-scale, rapid energy transition is hence also a unique opportunity.

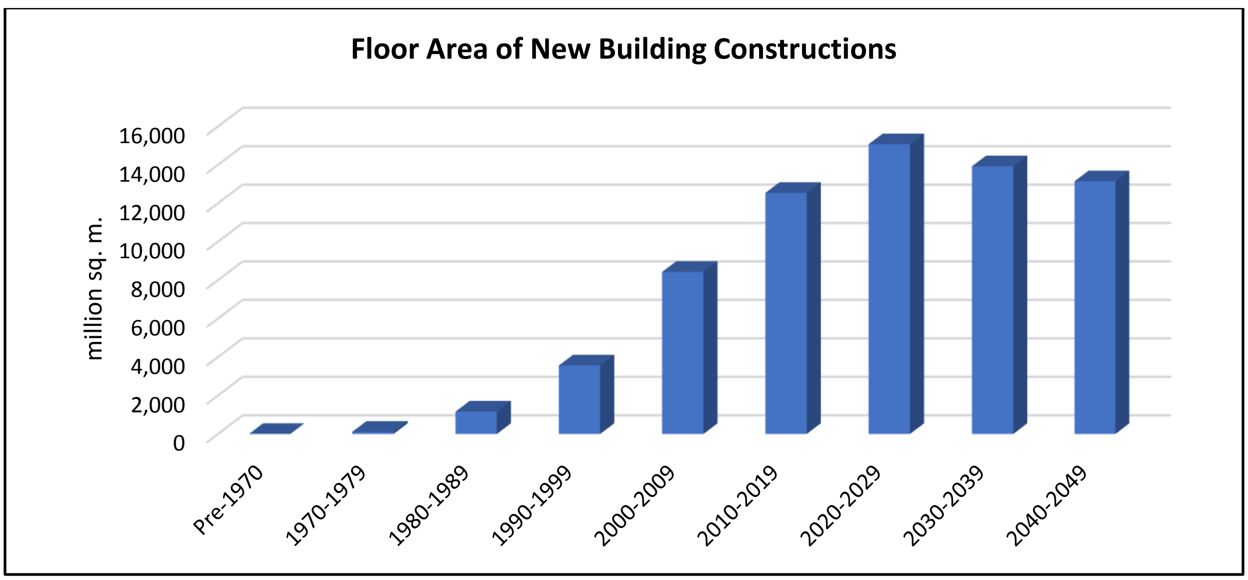


Figure 23: Projected new building construction in India by decade
Source: Estimates from model developed by the author

## 4.4 The Research Question

In view of this complex challenge and the urgency for corrective measures, the main research question posed in this chapter is:

***How can the diverse set of actors in the building sector be collectively influenced to adopt sustainable building practices?***

The follow-up questions that the research tries to answer are:

- *Who are the key players in the sector?*
- *How can information and communication technologies be used to connect these disparate players for a sector-wide transition?*

## 4.5 Methodology

The below methodology, contextualized to the developing country, is proposed to answer the research question and to design a strategy for engaging with the building sector and influencing it towards low carbon building practices. Treating the building industry as a collection of actors working toward individual rational interests or social obligations, this research examines the sociological and behavioural dimensions of decarbonizing the building sector. We start by first identifying the barriers to sectoral transformation. Then we parallelly analyze the individual stakeholders' perspective as well as the macro policy scenario that led to the current state of the system. Next, we identify the behavioural biases that can be overcome with interventions. In contrast to targeting all the identified biases, the research seeks to identify the leverage points that can bring the maximum change in the functioning of the sector.

Once the key stakeholders and the leverage points for maximal transformation are defined, we proceed to define the behavioural interventions that can be applied to each set of actors and the ways/tools to implement these interventions. We then evaluate whether a top-down approach targeting the regulators and builders or a bottom-up approach starting with the end users is most suited for the specific conditions. Finally, we collate our findings in the form a sectoral strategy for transforming India's building sector towards energy-efficient building practices.

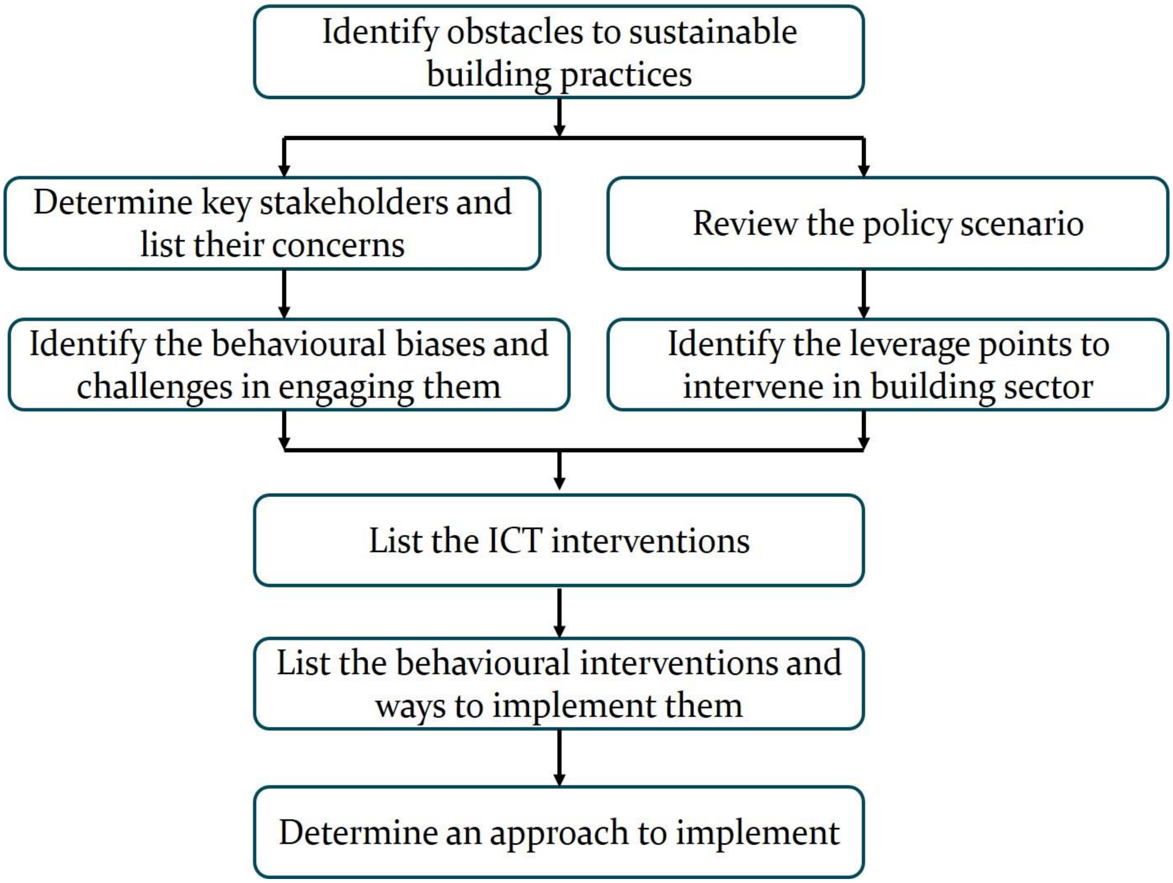


Figure 24: Methodology for sectoral engagement for behavior change

### 4.5.1 Barriers to sectoral transformation

Influencing the building sector in India towards sustainable construction remains a difficult, but not insurmountable, challenge. Several barriers need to be overcome for the sector to evolve.

(1) Inadequate information and incorrect perception: Although the prices of energy efficient buildings have reduced drastically in the past few years, most customers still believe that sustainable construction is expensive and has unreasonable pay back periods. In the absence of publicly available data, end users are unable to make an informed choice

(2) Established norms and cultural practices: The design and construction of buildings itself is influenced by social and cultural of the region. Hence it would be difficult to go against predominant traditions and challenge the status quo

(3) Lack of adequate incentives: The incentives provided by government agencies for the transitions is too little and non-uniform to make a meaningful impact among the developers and house owners
(4) Highly fragmented sector with complex inter-linkages: A diverse range of stakeholders, many of whom disconnected from each other are involved in the long life-cycle of the buildings. Due to the complexity and interconnected of different activities, dependence occurs only between actors directly interacting in similar activities, while being totally disconnected from the rest. No established processes exist for varied actors in the sector to cooperate and maximize the long-term energy efficiency of the building.
(5) Focus on commercial buildings: Guidelines and building codes focused only on large commercial buildings until now. Residential buildings targeting individual customers, which formed the bulk of the new construction, were not required to comply to energy efficiency standards.
(6) Priorities and vales of stakeholders vary: Interests of stakeholders often vary significantly and can sometimes be conflicting.
(7) Lack of participatory processes: Most of the building standards and regulations do not have mechanisms for all the diverse stakeholders to participate in the design and building processes

### 4.5.2 Policy scenario

Projections of energy use from our model (Figure 20) suggest that in the absence of specific sectoral policies to reduce the total emissions, the total energy demand (embodied and operational) from the Indian building sector is expected to increase by five-fold by 2050. Building codes and Building energy codes have been effective regulatory tools in reducing the energy intensity globally. In India too, the critical role of building energy efficiency has been acknowledged in the Intended Nationally Determined Contributions (INDCs) adopted in the 2015 UN Climate Summit in Paris. Therefore, as part of its National Action Plan on Climate Change, the Indian government developed the National Mission for Enhanced Energy Efficiency to address energy savings through energy-efficient appliances and demand-side management and the National Mission for Sustainable Habitat to address design and retrofit of buildings. Due to its vast size and the decentralized structure of the government, India has many central and state government bodies that draft, legislate and enforce building codes and energy efficiency standards. Of these, the most significant codes/regulations/norms are:

- National Building Code (NBC) (2016) by the Bureau of Indian Standards
- Energy Conservation Building Codes (ECBC) by the Bureau of Energy Efficiency
- Environmental Impact Assessment (EIA) and Clearance by the Ministry of Environment, Forests and Climate Change
- Voluntary green building rating systems

*National Building Code (NBC)*

The National Building Code is a comprehensive model code developed by Bureau of Indian Standards (BIS) a central Government body to guide municipalities and city development authorities to follow in formulating and adopting appropriate state-level building by-laws. It provides guidelines for regulating building construction activities. Energy efficiency is partly covered in a few aspects of design and construction of this voluntary code. Although the code is for country-wide adoption, the implementation is to be adopted by the urban local bodies (ULBs) of the state government. The NBC contains requirements, administrative regulations and stipulations for materials, building design, construction, water use and waste generation. Until recently, energy consumption of buildings was not a priority in the codes, and it was only in the amendment made in 2016 that a dedicated chapter on sustainability as well as sections on building materials production and standards were included to the NBC. Some of the salient and incremental features of the NBC (2016) are listed in Appendix G.

*Energy Conservation Building Code (ECBC)*

The Bureau of Energy Efficiency under the Ministry of Power had launched the ECBC in 2007 and improvised it in 2008 and 2017 to promote minimum standards for energy use in new buildings and retrofits of existing buildings.  Although it has been based on international standards, it has been amended to suit the different type of climatic zones (See Appendix F) within India. The code is prescribed for the design and construction of new commercial and public buildings having a connected load of 100 kW or 120 KVA. Buildings compliant with India's Energy Conservation Building Code (ECBC) are estimated to be 20% to 25% more efficient than conventional buildings.

The code is voluntary at the national level and implementation is left to enforcement by the state governments at the level of urban local body (ULB) (See Figure 25). ECBC permits a trade-off between prescriptive and performance-based compliance paths for achieving building energy efficiency. The prescriptive method of the code sets energy efficiency requirements for various building components such as building envelope, lighting, heating, ventilation and air conditioning, solar water heating and pumping and electrical systems such as transformers. And the performance-based method suggests a whole-building performance (WBP) approach to prove the efficiency of the building. At least ten states have enforced ECBC for all new commercial construction by updating the state's building bye-laws and notifying them in the state's gazette. However, for the implementation, these states still require substantial support for capacity building, for demonstration projects, for compliance and to prepare tools for monitoring and verification.

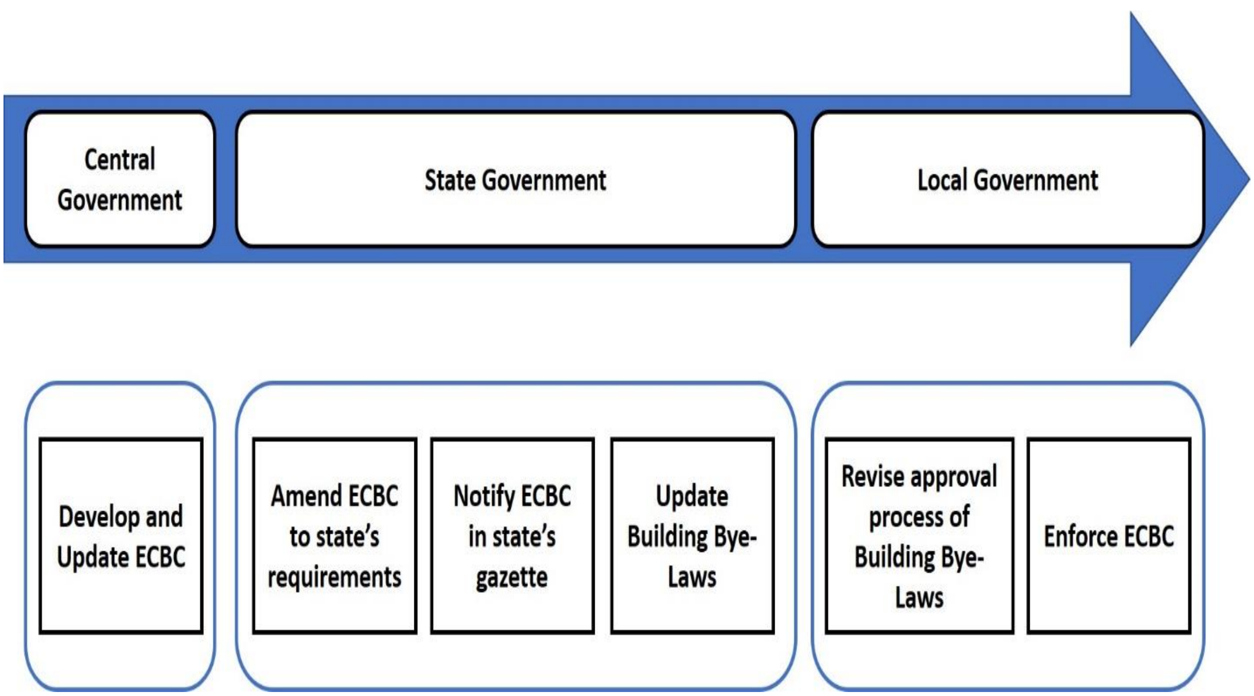


Figure 25: Implementation process of Energy Conservation Building Code

Source: Adopted from (Ganesan, 2017)

*Environmental Impact Assessment (EIA) and Clearance*

All project developers from resource intensive sectors (including the building sector) are mandated to get an EIA clearance from the Ministry of Environment, Forests and Climate Change (MoEFCC) before starting projects of size greater than 20,000 square meters. The EIA provides a comprehensive assessment of all resources use including land, air, water, energy and ecological impacts. Although EIA does not explicitly address energy efficiency, integrating it with other energy policies can have a significant impact to assuage the energy and carbon footprint of the built environment. The recent advancements in the National Building Code (2016) has accordingly incorporated essential features of EIA and mandates to all commercial and residential buildings of land area greater than 5000 square meters. When the state governments incorporate these guidelines into the Building Bye-Laws, Urban local bodies will be for the very first time starting to address the environmental impact of all medium to large residential buildings.

*Voluntary green building rating systems*

A "green building" rating system systematically evaluates the energy performance of a building and rates it according to a set of pre-defined parameters. Three green building rating systems currently exist that are designed for Indian climatic conditions: IGBC (Indian Green Building Council), GRIHA (Green Rating for Integrated Habitat Assessment) and BEE Buildings Star Rating System. Detailed features and comparisons between these green building rating systems are given in Appendix H.

- **Indian Green Building Council (IGBC) Rating System**

  IGBC is an Indian rating system, designed on the lines of the US-based LEED (Leadership in Energy and Environmental Design) certification. LEED-India is the localized version of it, which is administered by the IGBC, and hence the name. Different sub-types of the rating system are defined for different types of facilities such as residences, factories, campuses and for existing buildings, in conformance with the US Green Building Council.

- **Green Rating for Integrated Habitat Assessment (GRIHA)**

  GRIHA, developed and implemented by The Energy and Resources Institute (TERI) and the Ministry of New and Renewable Energy (MNRE) is India's national rating system for green building design. For buildings with fully air-conditioned interiors, GRIHA mandates compliance with ECBC (discussed above) and for buildings that are naturally ventilated, only a partial ECBC compliance is required. The rating is on a 5-stars (rating levels) scale, with 5 stars being the most efficient. Comparison of features of LEED and GRIHA is given in Appendix H.

- **BEE Buildings Star Rating System**

  The Bureau of Energy Efficiency (BEE) under the Ministry of Power developed a rating system based on the actual energy performance index (EPI) of constructed buildings. The actual performance of a building is measured in terms of specific energy – kWh/sq. m/year and is rated on a scale of 1 to 5 star. Higher the EPI, greater are the number of stars. The star rating normalizes the operational characteristics such as the type of operation, the hours of operation, the percent of conditioned space and the climatic zone in which the building performs. Such rating enables comparison to other buildings having similar business activities and operational characteristics.

Green building rating systems do play a role in encouraging energy-efficient building design and construction. However, most ratings fail to address the embodied energy of the materials, which form a substantial component of the total energy consumed by a building in its lifetime. Studies suggest that by replacing energy-intensive materials with low-energy materials and techniques, it is possible to cut down the embodied energy in buildings to almost half of conventional buildings. (Venkatarama Reddy & Jagadish, 2003). The methodologies used by the building rating systems too lack a holistic approach, and fail to incorporate key issues such as resource scarcity and the need to reuse materials and to recycle construction and demolition waste wherever possible (See Appendix H).

All the building codes and norms described above provide reasonable guidance for defining and encouraging the adoption of energy-efficient building practices. However, these codes achieve energy savings only when buildings comply with the codes. The guidelines provided in the National Building Code will reach their potential only when the states imbibe these guidelines and convert them into enforceable building bye-laws. Enforcement of building bye-laws is another major challenge, especially in developing countries where the pace of growth exceeds the pace of regulation and legislation. Most of these energy codes were voluntary until recent years and their mandatory enforcement requires additional technical and operational capacity from the implementing local bodies.

With more than 60% of building stock of 2050 yet to be built (Figure 23), India has a unique opportunity to go beyond the existing efforts of other developed and developing countries and avoid thousands of mega tons of carbon emissions. Dissemination of information and capacity building are crucial bottle necks that need to be addressed with utmost urgency. Absence of capacity building at the level of urban local bodies – where it is needed the most – has resulted in sporadic adoption of green building practices until now. Less than 10% of commercial buildings in India have some form of green building rating and the share of residential buildings as a share of total building stock is abysmally low.

A majority of the demand in the near future is expected primarily from the less-aware residential consumers. And in a demand-driven complex market such as the building sector, policy needs to address awareness creation and knowledge-sharing through publicly accessible platforms. Financial incentives such as lower registration fees and marginally lower interest rates for green-rated buildings do exist in a few pockets of the country, but the consumers are barely aware and do not make use of such incentives. Incentives for the builders in terms of a nominally higher floor-area-ratio (FAR) has been tried in a few cities, which generated only a tepid interest. Subsidies and incentives can only initiate an interest among the first few proactive users, which would then require the private sector and financial institutions to play a bigger role.  Access to finance for is a major area that has not been targeted in the policy until now. Novel financial mechanisms from banks that could convert the operational savings into lower upfront cost for the house owners is lacking in the current market.

The role of policy in bringing the required change is clearly evident. Standards for energy-efficient materials and products need to be created and adopted at the earliest. Encouraging the supply chains to adopt low-energy materials requires at a minimum Including less energy-intensive materials and recycled products in the schedule of rates in the Public Works Department. Reserving a fraction of public procurement for products and materials which are certified to be less energy intensive will reduce the prices of such materials and products and eventually pave the way for greater adoption by the private sector. Finally communicating the costs and benefits of sustainable buildings and products in public and online forums helps in creating awareness and in breaking down the inertia for novel technologies and products.

### 4.5.3 The key stakeholders

The building sector in India is very complex and the business relationships between the stakeholders is quite intricate (Figure 26). The sector is highly fragmented, with very little integration across the value chain. Most builders (also called project developers) are usually engaged in temporary, one-off projects. For each project, the developer interacts with a large numberof stakeholders such as architects, construction engineers, contractors and material suppliers, who usually differ per project. The project type and size is decided by the prevailing market conditions, customer demand, availability of land and the cost and reliability of resource supply. Regulatory compliance for energy efficiency is usually an after-thought in the whole process. Designers, engineers and contractors are bounded by the requirements specific to each project, without the certainty of similar requirements for a consequent project. Information deficit in consumer preferences and willingness to pay for resource-efficient green buildings is yet another source of uncertainty for the developers. Such short-term visibility for the builders, contractors and trade specialists often leads to knowledge that could not be extended beyond individual projects and rarely upgrade their skills unless the project demands it. Due to high uncertainty in the projects, most stakeholders are often reluctant to try newer technologies and postpone their decision to adopt more efficient solutions until they get confirmation from elsewhere about the viability of the solutions. Lack of adequate information to take decisions for application of latest technologies and methods is hence the foremost constraint in the sector.

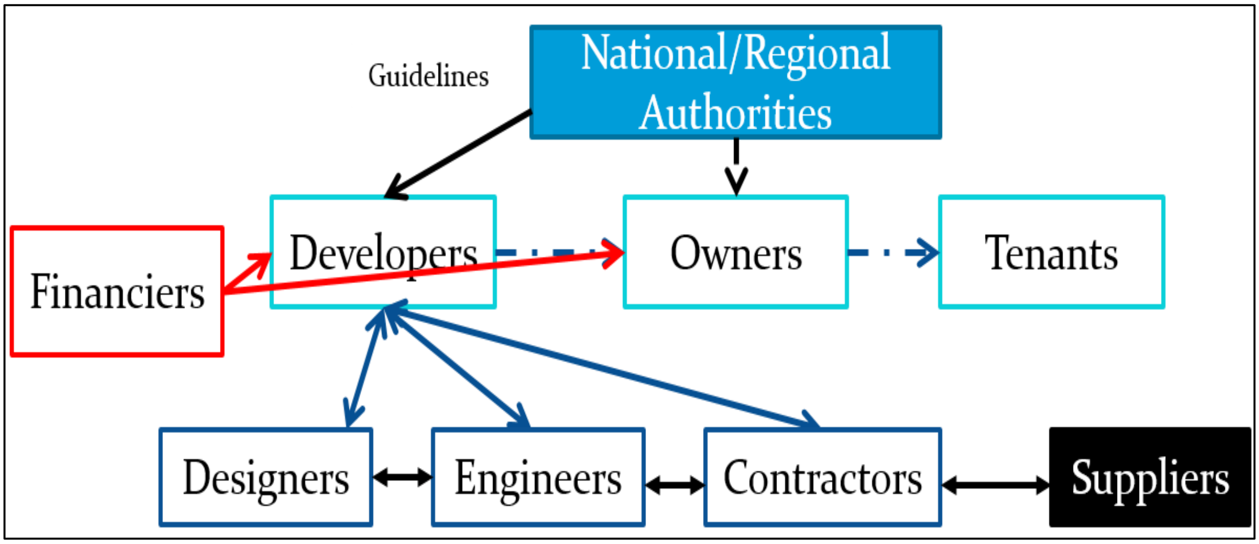


Figure 26: Key stakeholders in India's building sector

**Project Developers:** are the most crucial actors in the building sector. They are driven by short-term financial gains and are often speculative in their decision making. Developers are interested in implementing energy efficiency measures only when convinced of sufficient consumer interest. The lackadaisical approach to energy efficiency among the developers is mainly due to the principal/agent problem: in the absence of active consumer demand, the adoption costs are borne by the developer, while home buyers enjoy the benefit.

**National and Regional Authorities:** These could potentially influence the entire sector by enacting stringent policies for resource-efficient designs. However, in the Indian context, the authorities could be influenced by the lobbying capacity of the builder groups. The outcome is that only tooth-less guidelines and simple energy efficiency acts, primarily targeting the commercial buildings are enacted.

**Designers, Engineers and Contractors:** Although they have advanced knowledge in the techno-economic benefits, their influence on energy-efficient design is limited due to uncertainty in the builder's interest. However, in an integrated design process, they can be expected to have a bigger influence on the developer's decisions.

**Materials Suppliers**: They have the least power in influencing a decision and would stick to the requirements of conventional buildings unless mandated otherwise by the developer.

**Banks and Financial Institutions:** These are solely driven by the return on investment and base their decisions based on the past performance rather than future potential of the lenders. Their role in influencing the energy transition until now has been limited. However, with the increasing awareness of climate risks and with increased awareness of bankability of energy-efficient projects, they can play a crucial role in positively influencing both the supply side and the demand side of the sector.

**House owners:** They invest in the building for its market value and the rental value of the premise. They are usually price-conscious and most have unreasonably high discount rates for their investment. decisions. Some owners buy to sell (and make a capital return); others buy to lease (as an investment) or occupy. The last group is most likely to consider investments in energy efficient buildings that may have paybacks over several years.

**Tenants:** They enjoy most of savings in energy and resource use. However, data on their willingness to pay higher rents for resource-efficient buildings is still scarce.

A typical energy-efficient building design and construction includes all the above defined key stakeholders in an integrated development process, from the design team (project developers, architects, engineers and sustainability consultants) and the construction team (equipment manufacturers, contractors and materials suppliers) and finally the house owners and end users. Given the varied concerns for each of these stakeholders, invoking them towards collective behavior change requires identifying points of leverage and the key linkages that could galvanize the energy transition.

### 4.5.4 Concerns and behavioural biases of key stakeholders

Interviews with key stakeholders and focus group discussions with industry experts revealed the priorities and important behavioural biases that need to be addressed for each of the stakeholder types. Information gap is the most prominent bias observed across the sector. While on one hand, the developers were uncertain about the demand for sustainable construction, house owners and tenants are still less informed on key parameters such as return on investment, added market value and availability of incentives for green buildings. The second prominent behavioural bias is inertia or the status-quo bias. In view of unclear policy or oblivious to benefits, most of the stakeholders stuck on to conventional design and construction. In the absence of industry information on the payback and added value of sustainability investment, the financiers too stuck to their default lending methods. This could be corrected significantly by collectively defining efficient construction as the new defaults and by making green buildings as the new normal.

Table 22: Concerns and biases of key stakeholders

| | Key Stakeholders | Primary Concerns | Behavioural Biases |
|---|---|---|---|
| **Internal stakeholders** | **Real estate developers** | Economic feasibility<br>Return on Investment<br>Brand image<br>Policy risks<br>Market risks | Information gap<br>Status quo bias<br>Loss aversion |
| | **House owners** | Return on Investment<br>Rental value<br>Depreciation of asset value | Over-discounting<br>Mental accounting<br>Information gap |
| | **Tenants/End users** | Operational costs<br>Resilience of erratic energy and water supply<br>Life style and wellbeing | Information gap |
| | **Banks / Financial institutions** | Return on investment | Status quo bias<br>Information gap |
| | **Designers/Engineers** | Creative and effective application of technologies and processes | Status quo bias |
| | **Contractors** | Cost of technology<br>Cost of materials<br>Availability of skilled labour | Status quo bias |
| | **Materials Suppliers** | Availability of natural resources | Environmental illiteracy |
| **Regulatory stakeholders** | **National & Regional Authorities** | Regulation and Control<br>Carbon emissions<br>Energy and Water demand<br>Waste generated<br>Economic activity generated | Information gap |

### 4.5.5 The leverage points

We define leverage points as those key actions/players that could revolutionize the sector with critical changes that have a snow balling effect on the entire ecosystem. We note that the strongest reason for the sector's current lackadaisical approach to energy-efficient construction is the developer's uncertainty- uncertainty in customer demand and their willingness to pay for more green buildings. Capturing data on the potential size of interested and environmentally-aware customers can influence the developers' behavior and consequently the design, construction and supply chain. With a critical mass of knowledgeable tenants and house owners, the sector could be catalyzed for a larger uptake of sustainable construction.

The second leverage point is the critical role that the financiers could play in the transformation. As opposed to their current passive approach to lending, they could be informed about the unique selling points of the green building sector. Developers and house owners willing to adopt efficient measures are educated, responsible and hence be considered better borrowers. Providing relevant information on their socio-demographics and better capability for repaying can activate the financial sector. Prioritized lending, with lower interest rates and higher incentives for "green mortgages" can set the ball rolling with a renewed interest in green buildings among all the stakeholders.

Finally, engaging the authorities by informing them about the ongoing transformation could motivate them to play a more active role in the process. By bringing key information on the quantum of savings achieved, the potential size of the market and the resultant social benefits onto the public domain where numerous end users could express opinion, governmental institutions could be enabled to take better measures to better enable the system.

### 4.5.6 Role of Information & Communication Technologies for behavioural change

Most of the workforce in the sector is largely unskilled or semi-skilled. Project timelines are highly unpredictable and projects usually face severe delays due to uncoordinated efforts. The highly fragmented nature of the sector permits very little collaboration across the value chain. Poor contract documents, frequent design changes, rework due to workers' mistakes and untrained workforce are among the most important causes that adversely affect the productivity, as well as the quality of the output. A radical transformation of the sector requires a paradigm shift in the way the entire sector communicates, collaborates, designs, constructs and operates a building. Information and Communication technologies that could break the conventional barriers, "defragment" the fragmented sector and connect all the varied stakeholders, can potentially lead this fundamental transformation in how the building sector operates. While technologies by themselves could not be solely leading behaviour change, they have a tremendous amplifying effect in accelerating positive change by making people do things in newer and faster ways, more accurately and at a lesser cost.  Some of the promising new Information and Communication technologies that could impact this transformation are discussed below.

Table 23: Rationale for ICT-based interventions in the building sector

| Actions required | Rationale | Means to deliver |
|---|---|---|
| **Smarter Training and Education** | Severe shortage of skilled personnel. Excessive human errors and material wastage at site. Lackadaisical attitudes of workers towards the final outcomes. | Augmented and Virtual Reality tools can be employed to provide immersive learning in simulated work environments. |
| **Smarter Communication and Collaboration** | Poor communication among the varied stakeholders. Improper project documents with errors going undetected until the construction site. Mechanical, electrical and plumbing experts work in silos, with integration happening only in final stages. | Building Information Modeling and Virtual Reality can provide a collaborative platform for visualization, verification and monitoring at each stage of the project. Better integration of all project participants leads to elimination of conflicts. |
| **Smarter Design** | Critical decisions of design such as sizing of building components and the materials used are done without consulting the construction team. | BIM, with collaborative ways of customizing each component in a virtual environment helps in achieving the right outcomes. |
| **Smarter Knowledge Sharing** | Building contractors are mostly engaged in temporary projects. Disparate participants have no means of learning about good practices and successful innovations | An open, knowledge platform through which the industry, financiers and the clients can freely access information. |
| **Smarter Consumer Engagement** | Consumers get to see the building only after most of construction ends. Lack of engagement with consumers during key decisions such as material selection. | Virtual site visits help in taking customer feedback and to incorporate their inputs before the construction begins. Mobile applications help in engaging for sustained behavior change. |

*4.5.6.1 Building Information Modeling*

Building Information Modeling (BIM), is a promising technology that can revolutionize the way different participants in a building project can collaborate and save both time and money during the building lifecycle. BIM technology allows to digitally construct an accurate, virtual model of a building. This model, known as a "building information model", can be used for planning, design, construction, and operation of the building (Figure 27). It carries information such as the geographical location, geometry of the building, its spatial details, quantities and sizes of the building elements, types of materials, cost and manufacturer details, and the detailed project schedule. Architects, engineers, and constructors can visualize what is to be built in a simulated environment on a computer, generate drawings for the various building systems, estimate the materials and costs, generate the material orders and plan the delivery schedules for each of building components. In contrast to conventional 2D and 3D models, where any edit of the model by one project stakeholder requires a manual check and updating of all the independent documents and drawings, a building information model allows all components of the building model to be constantly responsive to changes and automatically regenerates the model.

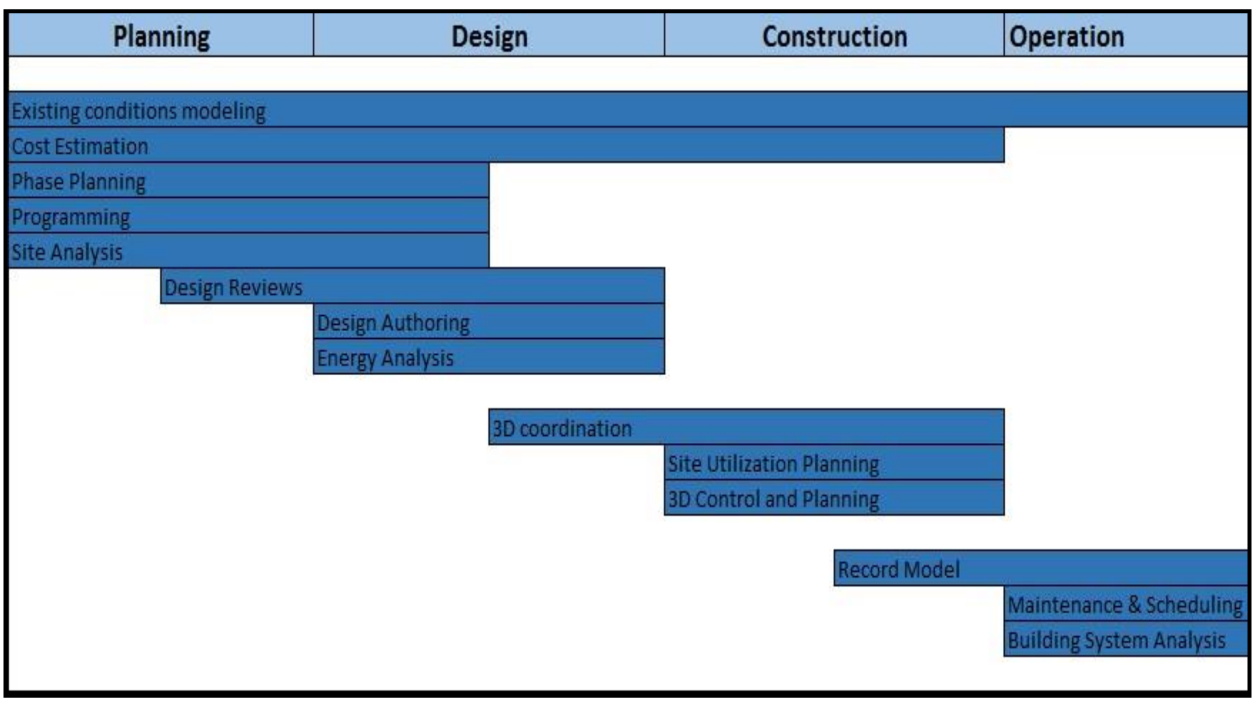


Figure 27: Primary uses of BIM throughout a Building Lifecycle

Source: Adopted from (Computer Integrated Construction Research Program, 2010)

BIM, as a process, can be introduced right from the beginning of the building project. It embraces the concept of Integrated Project Delivery, which brings expertise from contractors, fabricators, suppliers and product manufacturers together with design professionals and the project owner earlier in the process. This helps to produce a design that is optimized for quality, aesthetics, constructability, affordability and timeliness. Potential clashes between the different trades can be detected in the design phase, so that they can be planned for and avoided well ahead of time. Such effective coordination right from the planning stage until the completion of construction eliminates the need for redesign and rework, thereby avoiding cost and time overruns of the project. Using BIM therefore saves time and money, improves productivity, produces more detailed and accurate drawings, allows for better design decisions faster, produces high-quality construction documents, and substantially reduces building lifecycle costs.

Information is at the very heart of BIM. It stores and keep tracks of every piece of information generated during a building's lifecycle, enabling an easy sharing and reuse of useful information about each building component. For instance, in projects requiring pre-fabrication and modular construction, BIM enables easier extraction of specifications of building components for pre-fabrication and assembly at a lesser cost. After the building gets constructed, the BIM model contains an enormous amount of valuable data that can be leveraged to lower the building's operational costs. The operator will be able to find the precise location of each component and service it seamlessly. And finally, at the end of the building's useful life, BIM enables an efficient recovery of all reusable and recyclable resources which would otherwise end in a landfill. By closing the material loop, BIM eliminates the pervasive, linear pattern of material flow (Figure 14) and drives the sector towards a more sustainable circular economy model.

#### *4.5.6.2 Virtual Reality and Augmented Reality*

Many of the behavioural problems found in the construction sector are due to the inability of the builders, designers, engineers, and workers to perceive a project before it is built. Virtual Reality (VR) is a technology that overcomes this problem and permits the users to experience and interact with a building, in a completely simulated environment. Originally designed for gaming applications, VR can immerse the user in a virtually constructed environment i.e. user is made part of a virtual environment. Augmented Reality (AR), on the other hand, is a technology that overlays virtual information over the user's real world i.e., the virtual components are made to be felt as part of the user's real world (Figure 28). Users can experience the virtual environment through desktop computers and mobile devices (non-immersive) or by wearing VR headsets (immersive). Although these technologies are existing for more than two decades, recent technological advancements and increased affordability, have made them commercially ready to be deployed massively in several areas including the building sector. VR and AR are incredible tools that give the participants in the construction project a chance to immerse themselves into the project before spending months or years, constructing it. VR/AR finds many applications in the building sector including immersive off-site and on-site education, safety training, interactive design, improved construction planning and customer engagement.

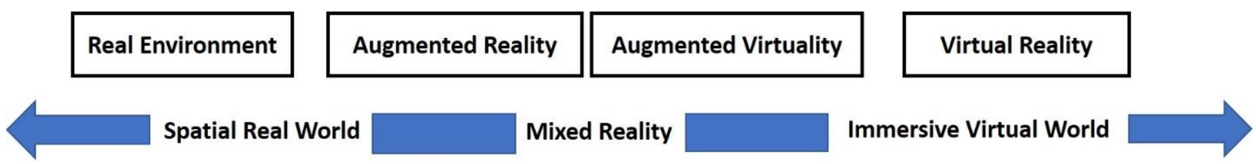


Figure 28: Real and Virtual Environments

- **Immersive learning**

The technology's ability to simulate realistic virtual training environments is an essential reason for the building sector with a focus on practical skill development and safety to adopt it. Training workers with VR/AR allows them to retain much more knowledge as compared to a classroom training. Considering that several thousand fatal accidents occur in the Indian construction sector each year, immersive training in life-life environments helps the workers to learn much faster without causing risk either to themselves or to the project. Off-site training can be enriched with virtual reality, which can visually deliver site-specific instructions to the trainees. By an accurate visualization of what the end-product would look like, workers can appreciate the design better and will be much more motivated to work towards a shared objective. VR/AR is a scalable solution to train thousands of unskilled workers to a very high standard, within a short time period, at a low cost.

- **Design and Construction**

One of the biggest barrier for transforming the sector is its fragmented nature of operation. Project documents and detailed designs made by one set of practitioners are not easily interpreted by a different type of practitioners, which often leads to errors arising from the drawing board, only to be realized at the construction site. The strongest impact of VR to the building sector is its ability to "democratize" the design process. Even a technically detailed 3D model of a building could sometimes fail to make the builder, the contractor or the workers appreciate the designer's vision. VR enables these participants to walk inside the virtual project and analyze the shapes and sizes of each component of the building and provide corrections where needed. This reduces the scope for misinterpretation of design drawings and remarkably reduces disputes among the stakeholders. Clear site awareness created by VR/AR permits workers to quickly fit components and fixtures into the exact locations with increased accuracy and lower delays. By allowing the design and construction professionals to visualize and interact with both the virtual and actual building components, and by allowing comparison of the "as-planned" and "as-built" status of the project, VR technology can erase the strict demarcation which exists between the design and construction phases. In other words, VR makes building design a truly participatory process.

- **Consumer engagement and Marketing**

A unique feature of VR to enable a better engagement with their clients is its lack of compulsion for geographical proximity. Clients located remotely could walk through the virtual project and assess if the finalized design looks and feels exactly how they had imagined it to be. Such immediate and accurate feedback enables quicker on-boarding of the clients, faster approvals by them and prevents last-minute changes due to misunderstanding. Despite being technologically less savvy, clients using VR can have a greater say in how they wanted their building, office or house to be. Specifically, for low-cost, affordable houses in India, where efficient space utilization is of utmost concern, VR permits the customers to visualize movement inside the houses before buying. With its immersive content, and inspiring 3D visuals, VR can energize the builder's marketing campaigns to a new high, thereby leading to much more sales. Support to 360-degree video by popular online channels such as YouTube is helping VR reach out many more potential customers through the social media.

#### *4.5.6.3 Mobile Phone Applications*

Mobile phone users worldwide number to almost 2 billion, of which at least 650 million users are from India alone (IDC, 2017). With increased affordability, growing access to the Internet, feature-rich "Smart phones" are soon expected to the default means of communication by the young population in India. These smart phones are loaded with advanced operating systems, fast processing power, large memory, high-resolution camera and a touch screen, which enables user interaction though mobile applications (or Apps). A data-rich two-way communication is now possible between the customer and the service providers providing the Apps – customers get to know of their consumption and costs; the service providers could get to know about the customer's demographical information, location, personal interests and other details.

Mobile applications are excellent ways to capture customers' behaviours, their keenness to participate in sustainability measures and their willingness to adapt their lifestyles. An inter-active and easy-to-use mobile application provides an effective means of engagement with end consumers, capture their preferences, their socio-demographics and their likelihood to follow energy-efficiency measures. The uncertainty hitherto in the customer demand for sustainable buildings, in their willingness to pay more and in their interest towards positive pro-environmental behaviours is now challenged with crucial information to make decisions.

Gamification in mobile applications is a new method that integrates the typical elements of game playing: scoring points, clearing levels, competing with peers, into mobile applications. While advocating sustainable consumption is a way to affect behaviour change, getting the masses to buy into it is not an easy task. "Green Gamification" overcomes this problem by employing the very same concepts that makes games appealing – a sense of fun, challenge, achievement, competition and rewards – into mundane daily tasks and behaviours that are needed for sustainable lifestyles. For challenging tasks such as long-term engagement with consumers for behaviour change, gamification provides many-short term, achievable goals to maintain engagement (Figure 29). By tapping into the fundamental human needs to be motivated, to be part of a greater cause and to see the impact of their pro-environmental actions, green gamification transforms customer engagement by making sustainability, innovative, appealing and fun.

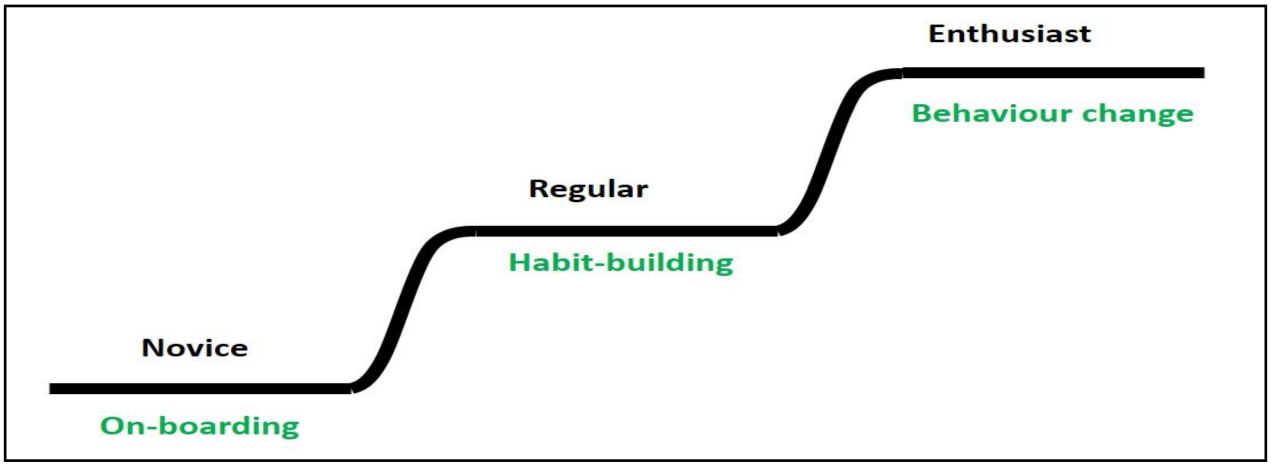


Figure 29: The Green Gamification journey

Source: Adopted from (Kim, 2012)

The building and construction sector currently contributes to about 8% of India's GDP. However, the sector's productivity at $2 per man-hour is among the lowest in the world (Barbosa et al., 2017). Structural changes among the sector's stakeholders brought about with the adoption the above ICT technologies, together with targeted behavioural interventions can drastically change the way the complex sector communicates, collaborates and operates. By steadily deploying each of these ICTs in the new building projects that would come up between now and 2030, we expect that the productivity of the sector can be brought to at least half that of the global sectoral average of $25 per man-hour. Given the immense size of the sector, the benefits accrued with these minimal improvements could be humongous (see Figure 31). The expected increase in revenues can more than compensate for the high initial cost of the ICT roll-out. Such a systemic, ICT-driven sector-wide strategy for behavior change can thus lead to a radical upheaval in the way the entire building sector communicates, collaborates and operates.

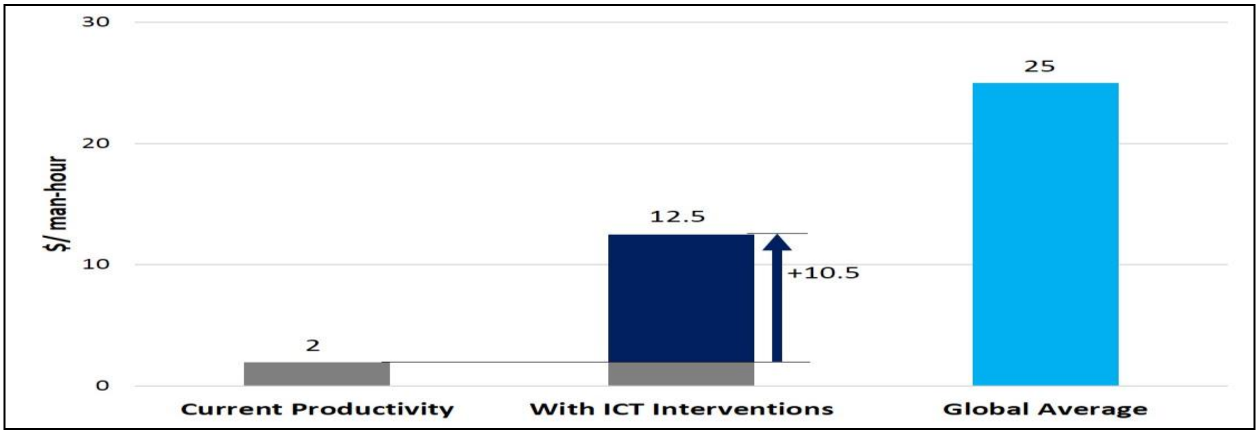


Figure 30: Labour productivity in building sector by 2030 with ICT interventions

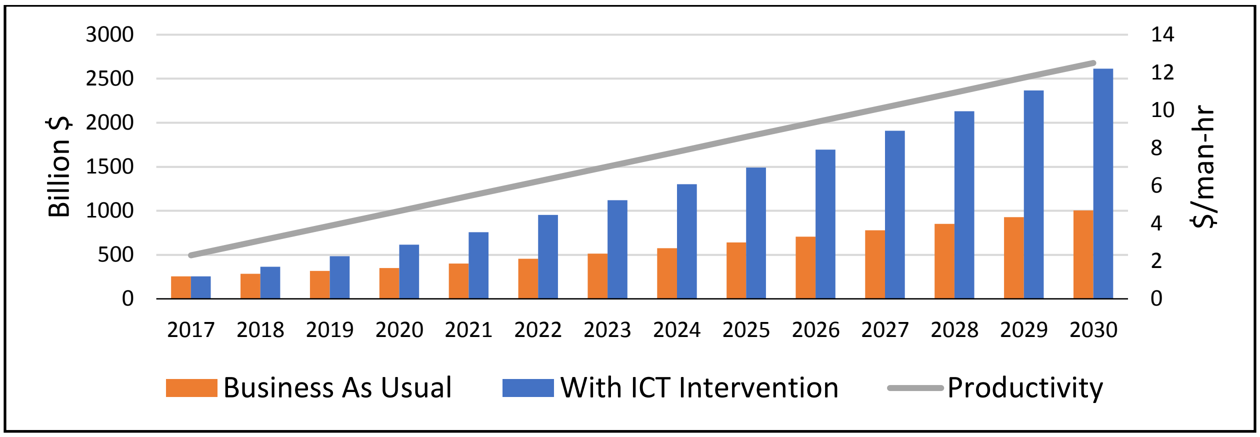


Figure 31: Projections of Building and Construction sector's contribution of to India's GDP with ICT interventions

### 4.5.7 Strategy for behavior change

The Indian building sector is growing unsustainably both in terms of its resource usage and energy footprint. There are enormous benefits to be gained for the country and for the planet by increasing its productivity and by reducing wastages. Most of the project delays and wastages are due to human factors and are totally avoidable (Yadav et al., 2017). Information deficit, lack of collaboration among the varied stakeholders and indifferent attitudes of the work force are among the primary behavioural causes for the inefficient way the sector operates. Bringing change in this sector is a highly daunting task, given the sheer size of the sector and un-organized way it operates. Understanding the barriers and the limitations of current policy let us explore the possibility of a radical transformation through the deployment of Information and

Communication Technologies that could shatter the conventional ways of changing one person and one stakeholder group at a time and attempt a simultaneous, sector-wide change.

Rapid developments in information and communication technologies (ICT) have made a plethora of computer-based applications easily accessible to most people. Information that once could be gathered through exhaustive surveys on sample populations can be now be obtained with computing power. Internet forums have enabled interested consumers to meet, discuss and collaborate with industry and authorities for bringing in positive change. Marketing and reaching out to environmentally aware individuals and consumer groups has become increasingly easier and more effective than reaching out through paper-based advertisements and posters. The Internet as a communication channel has enabled newer ways for communication and interlinkages between seemingly disparate stakeholders.

The end user who could make the maximum impact with his/her choice is the most important stakeholder. However most users are more concerned with the returns on their investment in property and are not aware of the added value of a green/sustainable building. The builders, who could lead the supply-side transformation, are unsure of the demand and are unlike to make the first move towards sustainability. The lack of means to capture customer interest and to estimate potential size of demand for sustainable buildings is the root cause of this problem. Web-based and mobile applications could fill in this crucial information gap, by capturing accurate details of customer interests and priorities, and by making data accessible easily to the wider audience. Public campaigns by government and non-governmental agencies can raise awareness on the additional market value of green buildings, their rental values, the lower operational costs and the slower rate of depreciation of asset value. Communicating the costs and benefits of sustainable buildings and products in public and online forums creates much larger awareness among the technically-savvy young people who would be buying their first home. Mobile applications can create a sense of competition for sustainable practices among the households. Voluntary pledges from potential customers could be informed to the builders, who could then gauge the potential size of market demand and start working towards meeting it in their upcoming projects.

Economic feasibility, brand image, policy risks and market risks are the major concerns of the project developers. An open-access, objective and efficient knowledge center is an urgent necessity to overcome their concerns. Builders and trade specialists can learn about good practices, about new innovations and about the performance of "green" companies and projects. Knowledge gained from demonstration projects adopting new technological practices such as BIM and VR, could be percolated across the supply chain, thereby leading to much more innovation. An integrated communication network for conveying exemplary results through editorials and blog posts go a long way in promoting innovation.

Banks and Financial institutions are another critical set of stakeholders, who until now played a miniscule role in promoting sustainable buildings. As the people who drive the finances into the sector, they have a unique opportunity to influence both the supply (project developers) as well as the demand (building owners and tenants). New financial innovations that can reduce the upfront cost or increase the repayment period can have phenomenal impact on increasing the demand. Including sustainability into their lending norms ensures that developers who implement sustainable building processes get preferential treatment, thereby increasing their market share and creating a further snowballing effect on the entire sector. Providing the financiers an easy access to an impartial knowledge network is the key to this transformation.

Government policy has a crucial role to play in the offtake of new technologies and products. Reserving a fraction of public procurement for products and materials which are certified to be less energy intensive will reduce the prices of such materials and products and eventually pave the way for greater adoption by the private sector. Mandating the inclusion of embodied energy in all "green building" certification ensures that the resource impact and energy footprint of the buildings get attention at the planning and design stages itself. Changing the eligibility criteria in public procurement, such that companies that are innovating by adopting new technologies such as BIM will have a huge ripple-effect, with the entire supply chain starting to adopt them. Creating a list of capability maturity of all project developers and contractors will reform the industry and eliminate the ad-hoc "cowboy" tradesmen who could otherwise create extensive damage with their inefficient, wasteful building practices.

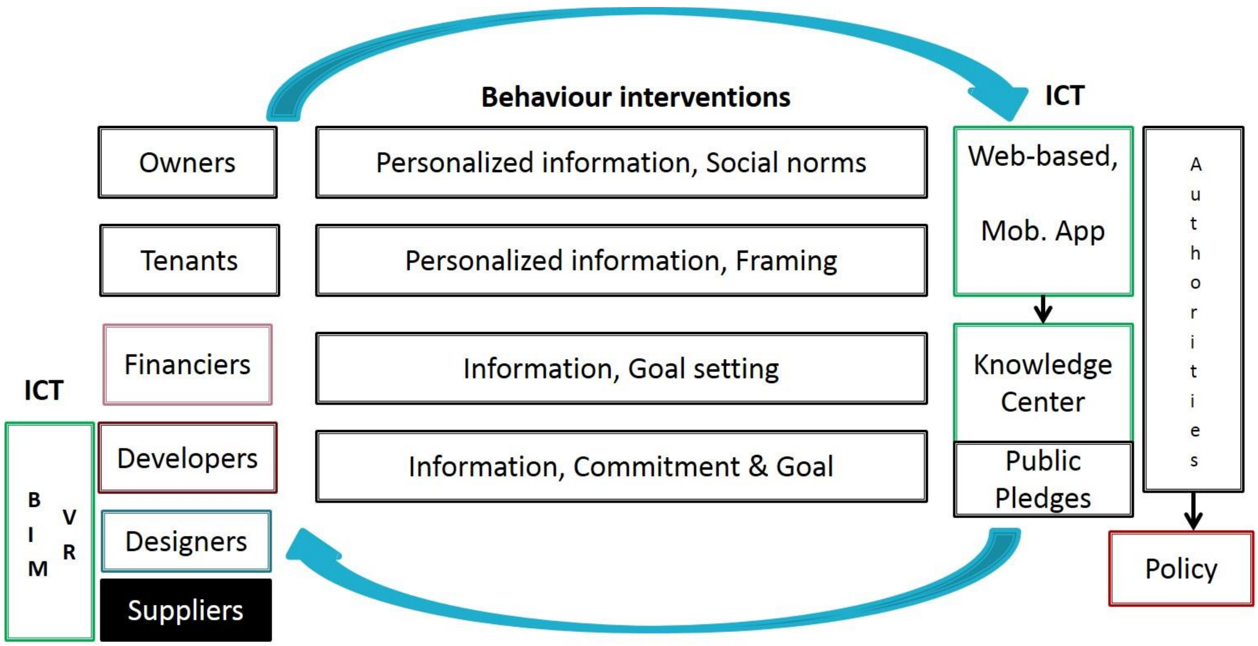


Figure 32: Sectoral engagement with behavioural interventions and ICT

Sharing all this information on public platforms that are accessible to the authorities is the next step for a positive feedback loop. Finally, involving the regional authorities into the process gives credibility to the strategy and helps gain further momentum to the process. As opposed to a top-down approach driven by policy alone, this bottom-up approach enables a rapid flow of information, create better synergies between the actors and enable faster decision making towards sustainable building. Behavioural interventions tailored to different types of stakeholders can be infused in this ICT-enabled approach (Figure 32).

## 4.6 Summary and Discussion

India, the fastest growing major economy in the world, is currently passing through a phase of rapid urbanization, with an estimated three-fold increase in floor area for residential buildings and a four-fold increase for commercial buildings by 2050 from a 2015 baseline. A gigantic quantity of resources and energy are expected to be consumed by its building sector within the next three decades– a consumption probably unprecedented in human history. Given that a vast portion of its building stock is yet to be built, this chapter focuses on the urgent need to drive India's building sector towards resource-efficient building practices.

This chapter first analyses the population, urbanization and consumption patterns and projects the resource, energy and carbon footprint of the industry until 2050. The problem of lack of accounting for the high embodied energy in the current building practices and inadequate nature of policies for reducing and managing resource wastage are highlighted.

Next, this study reveals that the major barriers to the decarbonization of the building sector in India are social and behavioural, rather than technical or economic. As opposed to a widely-held belief that the principal-agent problem (builder doesn't benefit from efficiency measures) is primarily responsible for the slow adoption of energy-efficient building practices, this study reveals that the highly-fragmented nature of building sector and the complex inter-linkages dissuade any rapid changes to the system. This chapter then identifies the key stakeholders and voices out their primary concerns and behavioural biases. Key leverage points for enabling a rapid transition are then listed.

Rather than mere philosophical rumination about a change in attitudes, this study provides a clear description of social and behavioural barriers to decarbonizing the building sector and defines a sectoral engagement strategy for a systemic behavioural change. A bottom-up approach is proposed, starting from demand generation for sustainable buildings, and ending with government engagement. A combination of stakeholder-specific behavioural interventions and information communication technologies are proposed to influence a sectoral behavior change. Such a sector-wide strategy for accelerating the adoption of low-carbon practices and technologies in buildings will encourage greater market absorption of new innovations, lower global carbon emissions and serve as an economic driver, especially for developing countries.

# Chapter 5: Findings and Conclusions

Environmental degradation and climate change are the outcomes of unsustainable human behaviours to meet their energy needs. Studying the human dimensions of a clean energy transition is a critical first step for engaging with them and persuading them towards more sustainable energy consumption behaviours and lifestyles. Several attempts to control or modify energy behaviours were made in the recent decades. There is now a critical need to reflect on these attempts, understand to what extent and under what conditions they were successful and the level to which individuals and the society has progressed in this clean energy transition.

The systematic literature review conducted in the beginning, revealed a comprehensive list of behavioural interventions that were tried out in the energy sector, each backed with socio-psychological theories. Quantitative methods aimed at individuals were clearly the favourite of most studies, with qualitative inputs being relegated to the side-lines of the inferences. Information provision was the most preferred choice of intervention. The use of "Smart" meters and devices has been increasingly observed as an instrument for intervention. However, no substantial relationship could be found between the additional information provided by these devices and the actual change in energy behaviours. In fact, during the review, better results were observed when individuals interacted with their peers, shared knowledge and felt being part of a bigger cause. This leads to an important introspective question: What makes a smart energy system SMART? This research suggests that devices and contraptions could only give additional data to make the users more aware. However, this awareness could be meaningful if and only if it could change attitudes towards energy consumption and persuade the end users towards affirmative actions. Hence the definition of a smart energy system could possibly be revised to include the "smart" energy consumers who could make wiser decisions – decisions that could transform and sustain the energy system.

Most energy policies attempt to treat the "irrationational" behaviour of consumers through well-intended measures and interventions. However, the personality traits that define what type of individual a person is, can affect the policy's impact. Less educated people may not have the same capability as the educated ones despite being made aware of their choices. The poorer sections of the society, having much more urgency for basic needs, tend to discount the future much more while making energy choices, despite such choices making them worse-off in the longer run. Behaviour interventions targeting individuals show varied results for varied kinds of individuals. Policies that fail to acknowledge such individual differences in traits, capabilities and constraints cannnot expect to have a larger success in implementation. This is equally relevant to the aging societies that fail to make economically rational choices, as well as to the poorer societies that could not make wiser decisions for the longer term.

Targeting individuals for energy efficiency and energy conservation can bring only as much change as the society and their cultural sphere permits them to. But individuals never act on personal beliefs alone and are often guided by the wider environment in which they live and operate. Knowledge and positive change for sustainable energy behaviours arise in individuals after a continous interaction with several other individuals of the population that together constitute the energy consumers. Hence, to affect changes at the level of the population, policy needs to consider the intricate interconnections among the members of the society and target the behaviours of multiple stakeholders simultaneously. Such a “system-wide” behaviour change approach requires identifying the key leverage points of engagement and a simultaneous engagement with the collective intelligence of these leverage points.  Policies that fail to address the wider societal context with a systemic approach are likely to have limited success on changing energy behaviours at the population level.

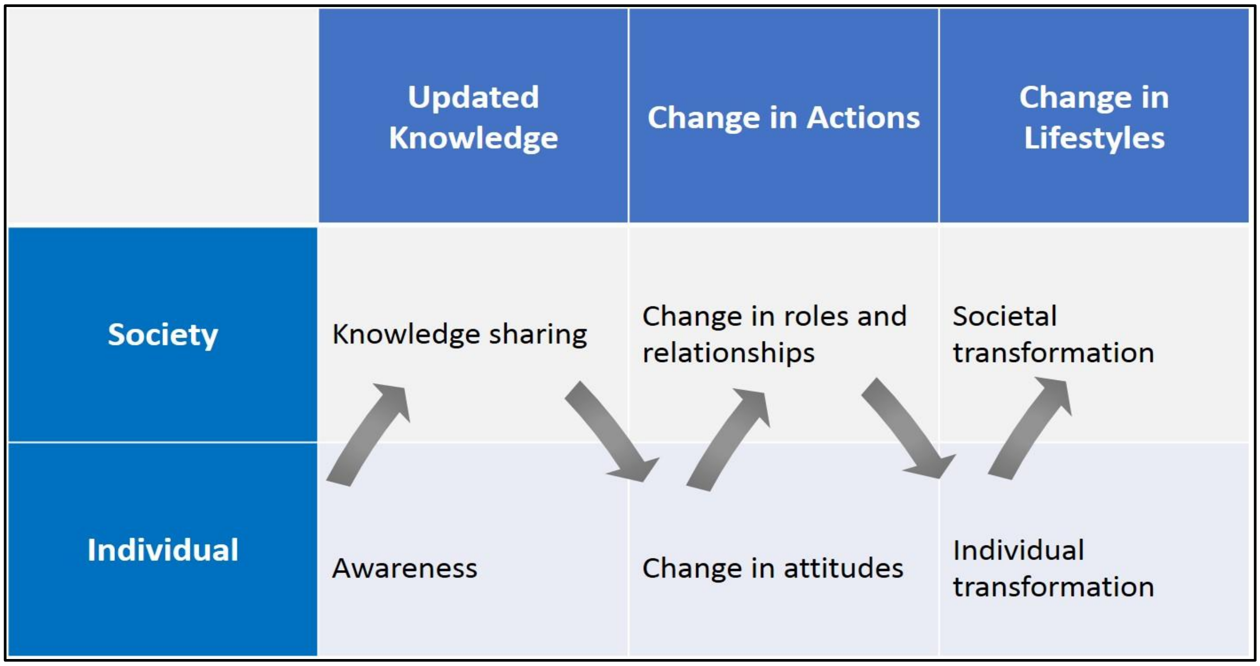


Figure 33: Interaction between the Individual and the Society for Behaviour Change

The principal findings from the research are mentioned below.

**1. Persistent behaviour change in energy consumption needs a sustained engagement**

Consumers are more engaged in energy-saving activities with a more informative bill that lucidly explains their consumption pattern and lists specific actions to be performed. Framing the benefits of such actions in social terms of health and well-being can induce more energy savings than by focussing on cost savings alone. When targeting large commitments of energy savings, a 'foot-in-the-door' technique with incremental requests to the energy consumers can be more effective than persuading them for one single large commitment. When commitments for proenvironmental behaviours are made in public, energy consumers subject themselves to more societal interaction and this societal pressure drives them to sustain their behaviours for a longer term.

**2. A continuous feedback loop is vital to drive change**

Change, either in an individual or a complex system, is often resisted due to inertia. Hence it is of utmost importance to display the outcome of any positive action. An instantaneous display allows the energy users to directly see the impact of their actions and modify them accordingly.

The most productive type of energy consumption feedback is the one that is the most instantaneous, frequent, tailored, interactive, disaggregated and salient. It is not sufficient to merely provide accurate or detailed information. Rather, it is how the feedback is presented, that decides if the consumers are informed, engaged and willing to change their consumption behaviours. All new measures and policies to roll out “smart” devices in consumer premises must first ensure that the feedback provided is relevant, useful, intelligible and easy to interpret, to gain the consumers’ trust and involvement.

**3. Not all energy consumers are equally capable to make rational choices**

Less-educated people and people who are not the primary financial decision makers tend to procrastinate their energy-efficiency purchases more than the rest of the population. Countries with a rapid aging population seeem to operate appliances for much longer than the expected lifetime of appliances. Acknowledging such individual differences in energy policy helps to draft policies that are more effective in covering the wider sections of the society.

**4. Energy policy for behaviour change must consider equity and fairness**

Economically disadvantaged people such as the elderly and low-income groups usually consume lesser energy than the average population but are more sensitive to price changes. They tend to be much more focused on the present and discount the future much more than the normal. Sections of the policy must specifically target these less-capable people with simpler ways of inducing behavioural change. Sections of policy could include conscious actions such as targeting the “mental accounts” of such people and naming the incentives and subsidies with easily recallable names of the specific action required, thereby gently nudging them.

**5. Transforming a complex system requires understanding the bigger picture**

Policies that focus on changing the energy behaviours of individuals alone will have a limited impact at the population level. Societies, sectors and organizations that comsume vast amounts of energy are complex systems with intricate interconnections between multiple stakeholders. Behaviour of such systems are not simply the linear addition of its components, and have norms and attitudes of their own. Behavioural change at a societal level requires identifying the intricate interlinkages and the leverage points that could produce maxium impact with minimal effort. Transforming the larger sized sectors for clean energy transition therefore requires effective engagement with key individuals simultaneously at multiple levels and establishing new paths of influence to drive the required change.

**6. Energy policy must embed “libertarian paternalism”**

Policy must achieve energy transition by actively engaging with the energy consumers. However, this must be done with a libertarian, instead of an authoritative outlook. Persuasion should precede any form of legislation. Social acceptance of the policy initiatives must be achieved with multiple instruments bundled into a single policy “package”, having a simple, consistent and sustained strategy for engagement and implementation. Lastly, feedback from the consumers on the effectiveness is important to monitor the progress and make the policy much more effective.

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# Appendices

## Appendix A: List of studies reviewed

| Study, Investigators and Experiment Design | Objectives of the study | Behaviour interventions | Findings/ Maximum energy savings generated | Sample size | Duration |
|---|---|---|---|---|---|
| Behavioral approaches to residential energy conservation<br>Seligman et al. (1978)<br>Three Randomized Controlled Field Experiments | To determine the effects of an immediate consumption feedback<br>To test the hypothesis that feedback would lead to more energy conservation if individuals were asked to adopt a difficult conservation goal rather than an easy one. | Daily feedback with state-sensing information;<br>Goal-setting | 10.5% savings in Trial 1<br>13.0% savings in Trial 2<br>15.7% savings in Trial 3 | 29 households;<br>100 households;<br>40 households | 1 month |
| Behavioral opportunities for energy savings in office buildings: a London field experiment<br>Miller (2013)<br>RCT field experiment | To increase the number of computer monitors turned off by employees during non-working hours. | Social feedback;<br>Public commitment | 40.4%;<br>50.4% | 1199 computer monitors | 2 months |
| Bridging the Energy Efficiency Gap: A Field Experiment on Lifetime Energy Costs and Household Appliances<br>Kallbekken et al. (2013)<br>Quasi-experimental design | To influence sale of energy-efficient electrical appliances | Information provision through energy labeling;<br>Interaction with sales staff | 2.3% through labeling alone<br>4.9% through combined treatment | 6 mega stores of appliances | 5 months |
| Cash by any other name? Evidence on labeling from the UK Winter Fuel Payment<br>Beatty et al. (2014)<br>Quasi-experimental design | To test the effect of labeling fuel payments | Information framing | 44% more likely to spend the payments on intended fuel | 10749 observations | 8 years |
| Are consumers willing to switch to smart time of use electricity tariffs? The importance of loss-aversion and electric vehicle ownership<br>Nicolson et al. (2017)<br>Randomized Controlled Laboratory experiment | To check if loss-framed messages are likely to overcome loss-aversion to switch to time of use tariffs | Message framing in terms financial losses | A third of energy users are in favour of switch to STOU tariffs. However, over 90% of energy bill payers are loss-averse and therefore statistically less willing to switch | 2020 participants | NA |

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| Neighbors, knowledge, and nuggets: Two natural field experiments on the role of incentives on energy conservation<br>Dolan & Metclafe (2015)<br>Two natural field experiments | To test both social norms on their own and the impact of feedback in combination with the norms;<br>To experimentally understand the interaction of financial rewards with social norms | Information provision;<br>Feedback<br>Social norms;<br>Financial incentives | 6% for Experiment 1 with joint effect;<br>8% for experiment 2 with financial rewards alone<br>strength of the financial incentive is reduced when social norm information is provided | 569 households;<br>2142 households | 2 years;<br>7 months |
| A group contingency for electricity conservation in master-metered apartments<br>Slavin et al. (1981)<br>Longitudinal study on 2 apartment blocks | To evaluate the effects of a group contingency on electricity conservation | Information provision;<br>Feedback<br>Group goals with Financial incentives | 6.2% for first apartment block;<br>6.9% for second apartment bloack | 166 apartment units | 15 weeks |
| Barriers to Consumer Choice of Energy Efficient Products<br>Anderson & Claxton (1982)<br>Natural field experiment | To assess the impact of refrigerator energy labels on consumers' purchase decisions | Information provision | 14% of energy conservation<br>Energy information was most effective in the low price market segment | 569 refrigerator purchases | 6 weeks |
| Measured energy savings from a more informative energy bill<br>Wilhite & Ling (1995)<br>Randomized Controlled Field Experiment | To test whether a more informative energy bill will result in in more efficient energy use in home | Information provision;<br>Enhanced and frequent feedback | 10% savings with a more informative bill | 1450 households | 3 years |
| New approaches for household energy conservation—In search of personal household energy budgets and energy reduction options<br>Benders et al. (2005)<br>Randomized Controlled Field Experiment | To test the effectiveness of personalization and feedback using a web-based tool on both direct and indirect energy requirement | Information provision (personalized reduction options);feedback | 8.5% for direct energy<br>Reductions in indirect energy was not significant | 300 households | 5 months |
| Real-time feedback and electricity consumption: a field experiment assessing the potential for savings and persistence<br>Houde et al. (2013)<br>Natural field experiment | To obtain an estimate of savings potential for real-time feedback technology | Real-time feedback | 5.7% savings<br>Significant declines persisted up to 4 weeks. As time passes, morning and evening intervals show larger reductions. | 1743 households | 3 months |

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| Effects of feedback on residential electricity demand—Findings from a field trial in Austria<br>Schleich et al. (2013)<br>Randomized Controlled Field Experiment | To test the effects of feedback provided by a web portal and by post | Indirect feedback<br>Near real-time feedback | 4.5% savings<br>Effects of feedback were most pronounced in the 30th – 70% percentile of electricity consumption; Feedback provided via a web portal and by post appears equally effective. | 1525 households | 1 year |
| Reducing Household Energy Consumption: A Qualitative and Quantitative Field Study<br>Brandon & Lewis (1999)<br>Randomized Controlled Field Experiment | To simultaneously compare the effect of seven feedback conditions | Information provision; Indirect feedback; Information framing | 4.84% savings to 4.46 increase in consumption for 7 different framing and feedback conditions | 120 households | 9 months |
| How Smart are Electricity Users with 'Smart Metering'? A Behavioural Economics Experiment<br>Bager & Mundaca (2015)<br>2 Randomized Controlled Field Experiments | To examine how behavioural biases affect consumers' response to energy-use information provided through smart meters | Near-real-time Feedback with SM; Framing: Loss-aversion<br>Information provision: nightly electricity use | 6.7% with SM feedback alone<br><br>18% absolute change (5.2% relative change)- Loss aversion and SM feedback<br><br>28% absolute (12.8% relative) for stand-by consumption with Loss aversion and SM feedback | 47 households; 16 households | 5 weeks |
| Does Information Feedback from In-Home Devices Reduce Electricity Use? Evidence from a Field Experiment<br>Attari et al. (2014)<br>Randomized Controlled Field Experiment | To investigate the effect of plug-level in-home devices<br>To test : the effect of feedback and its persistence<br>and the consumer characteristics that predict the largest behavioural change from feedback | Near real-time disaggregated plug-level data using multiple "Modlet" in-home devices | 12-23%, Savings were concentrated among those reporting higher Willingness-to-Pay for energy monitoring system | 101 apartment units | 30 months |
| The Dynamics of Information Framing: The Case of Energy Conservation Behaviour<br>Asensio & Delmas (2014)<br>Randomized Controlled Field Experiment | To test the novelty and persistence effects of two message framing approaches | Message framing: Health frame; Cost savings frame | 27.2 % peak conservation potential under health farme;14.9% under cost savings frame<br>Net 6% energy savings | 118 households | 8 months |

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| Joint effect of feedback and goal setting on performance: A field study of residential energy conservation<br>Becker (1978)<br>Randomized Controlled Field Experiment | To test the joint effect of Feedback and Goal setting on performance | Feedback;<br>Goal setting | 13% Feedback & Difficult goal;<br>4.6% Feedback & Easy goal;<br>1.3% Difficult goal;<br>1.2% Easy goal<br>Improved performance was a result of the joint effect of feedback and goal setting. | 100 households | 4 weeks |
| Smart meter devices and the effect of feedback on residential electricity consumption: Evidence from a natural experiment in Northern Ireland<br>Gans et al. (2013)<br>Longitudinal Observation study | To estimate the effect of real-time usage information on residential electricity consumption | Information provision;<br>Prepayment with Keypad meters technology | 11-17% | 45149 observations from 750,000 residential customers | 5 years |
| Knowledge is (Less) Power: Experimental Evidence from Residential Energy Use<br>Jessoe & Rapson (2014)<br>Randomized Controlled Field Experiment | To test the effect of high-frequency information on price elasticity of demand | Information provision on pricing;<br>Real-time feedback with In-Home-Devices | 12-18% (Price+IHD)<br><br>0-7% (Price-only)<br>Informed household are three standard deviations more responsive to temporary price increases. | 437 households | 2 months |
| Overcoming Salience Bias: How Real-Time Feedback Fosters Resource Conservation<br>Tiefenbeck et al. (2016)<br>Randomized Control Trial | To test if real-time feedback on a specific behavior can induce large behavioral changes. | Real-time Feedback with smart shower meters | 22% less water consumption<br>1.2 kWh savings per day | 697 households | 2 months |
| Bainbridge Energy Challenge. Energy efficiency and conservation block grant (EECBG) - Better buildings neighborhood program<br>Kraus (2014)<br>Longitudinal observational study | To observe the impact of a combination of interventions and home upgrades for a community | Community level feedback;<br>Information provision;<br>Non-price framing | 30% electricity savings (through a combination of measures and home upgrades) | 977 households | 3.5 years |
| Effecting Durable Change<br>Staats et al. (2004)<br>Quasi-experiment with longitudinal study | To investigate if information, feedback and social influence increased the strength of intentions to explain behavior change | Information,<br>Feedback,<br>Social interaction among participants | 6.7% savings on water consumption;<br>32.1% on solid waste deposition;<br>16.9% Natural gas;<br>7.6% Electricity | 150 households | 3 years |

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| On the magnitude and persistence of the Hawthorne Effect -Evidence from four field studies<br>Tiefenbeck (2016)<br>Randomized Controlled Trial with longitudinal study | To gauge the magnitude and time dynamics of the Hawthorne effect | Real-time feedback | 5-20% reduction in savings from the initial level | 642 households | 2-6 months |
| Using Social Cognition and Persuasion to Promote Energy Conservation: A Quasi-Experiment<br>Gonzales et al. (1988)<br>Quasi experiment | To determine if the effectiveness of a Home Energy Audit Program could be improved by training auditors to use socio-psychological principles during the audit procedure | Information provision; Information Framing: Losses rather than gain | Customers served by the trained auditors reported a greater likelihood of acting on the auditors' recommendations, and a large number of these customers reported applying for utility programs to finance retrofits. However, A longitudinal measure of actual energy | 408 customers | 2 weeks |
| Advertising Energy Saving Programs: The Potential Environmental Cost of Emphasizing Monetary Savings<br>Schwartz (2015)<br>Randomized Controlled Trial in laboratory | To examine how consumers' willingness and reasons to enroll in energy-savings programs are affected by framing extrinsic versus intrinsic motivations | Framing: Environmental and Monetary framing | Emphasizing a program's monetary benefits reduced participants' willingness to enroll. | 1172 individuals | NA |
| Nonprice incentives and energy conservation<br>Asensio & Delmas (2015)<br>Randomized Controlled Trial | To investigate non-price (environment and health-based ) messaging as a behavioral strategy to reduce energy use in the home and promote energy | Feedback: appliance-level real-time feedback; Message Framing: | 8% (average)<br>19% -for families with children | 118 households | 8 months |
| Finding the right shade of green: the effect of advertising appeal type on environmentally friendly consumption<br>Green & Peloza (2014)<br>Randomized Contolled Trial in laboratory | To examine the role of decision-making and consumption contexts on the efficacy of appeals that highlight consumer benefit and societal benefit. | Appeals Framing: Self-benefit VS Other-benefit appeals | In contexts where consumers experience heightened public accountability they are more responsive to other-benefit appeals, and in more private settings they favor self-benefit appeals. | 124 students | NA |
| Exploring the effectiveness of social messages on promoting energy conservation behavior in buildings<br>Khashe et al. (2016)<br>Randomized Contolled Trial in laboratory using Immersive Virtual Environment | To investigate the effectiveness of incorporating social influence methods: foot in the door & reciprocity, in the design of energy saving messages in buildings | Social influence methods | Reciprocity received significantly higher rates of compliance both in virtual and physical environments. Significant effects were found between participants' personality traits and their compliance with messages. | 150 students | NA |

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| Making energy visible: A qualitative field study of how householders interact with feedback from smart energy monitors<br>Hargreaves et al. (2010)<br>Qualitative evaluation of a Randomized Controlled Field Trial | To explore qualitatively how UK householders interact with real-time displays or SEMs | Real-time Feedback with Smart Energy Monitors | They observe that smart energy monitors are only as good as the household, social and political contexts in which they are used. | 275 households | 1 year |
| Keeping energy visible? Exploring how householders interact with feedback from smart energy monitors in the longer term<br>Hargreaves et al. (2013)<br>Observational study | To test whether or not the impact of Smart Energy Monitors (SEM) are durable over time | Environmental message framing | New feedback provided by smart energy meters gets "backgrounded" with time and after this, household behaviours may become harder to change | 275 households | 1 year |
| Making Energy Efficiency Pro-Poor: Insights from Behavioural Economics for Policy Design<br>Never, (2014)<br>Qualitative evaluation of 3 Natural Field Trials | To examine how behavioural factors can improve energy efficiency policies directed towards poor populations | Framing;<br>Financial incentives;<br>Message framing;<br>Social norms | The social acceptance of an energy efficient product or service in a community increases the perceived social affordability | 3 case studies in Africa | NA |
| Partitioning default effects: Why people choose not to choose<br>Dinner et al. (2011)<br>2 Randomized Controlled Trials in laboratory | To examine the possible causes of default effect in the choice of a light bulb | Choice Architecture<br>Information provision<br>Message framing | 39% more participants chose CFLs in "Default" condition as compared to the condition when Incandescent bulb was the default | 209 participants;<br>126 participants | NA |
| Using Non-Pecuniary Strategies to Influence Behavior: Evidence from a Large Scale Field Experiment<br>Ferraro & Price (2011)<br>Randomized Controlled Field Experiment | To examine the effect of norm-based messages on residential water demand | Technical advice;<br>Framing appeals for social behaviour;<br>Social norms | 5.62% reduction in water use with gradual waning of treatment effects | 100,000 households | 4 months |
| Using in-home displays to provide smart meter feedback about household electricity consumption: A randomized control trial comparing kilowatts, cost, and social norms<br>Schultz et al. (2015)<br>Randomized Controlled Trial | To examine the potential for a normative feedback message frame in the context of smart meters. | Feedback with In-Home-Device<br>Framing:<br>Feedback<br>Cost<br>Social normative frame | 9% in 1-week evaluation period;<br>7% in full 3-month evaluation period | 431 households | 3 months |

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| What goes on behind closed doors?: How college dormitory residents change to save energy during a competition-based energy reduction intervention<br>Nicole et al. (2016)<br>Longitudinal study of natural field experiment | To evaluate the impact of a competition-based intervention combining high-resolution electricity feedback, incentives, information and prompts on college dormitory residents' energy consumption and participation in demand response events. | Information and prompts;<br>Realtime Feedback<br>Financial incentives;<br>Social influence through competition | 6.4% during competition period | 39 suites in student residenc e; | 3 weeks |
| The effect of tailored information, goal setting, and tailored feedback on household energy use, energy-related behaviors, and behavioral antecedents<br>Abrahamse et al. (2007)<br>Randomized Controlled Field Trial | To examine whether this combination of interventions would result in (i) changes in direct and indirect energy use, (ii) changes in energy-related behaviors, and (iii) changes in behavioral antecedents (i.e. knowledge). | Tailored information;<br>Tailored feedback using an internet-based tool;<br>Goal setting; | 5.1% savings | 189 househol ds | 5 months |
| The Constructive, Destructive, and Reconstructive Power of Social Norms<br>Schultz et al. (2007)<br>Randomized Controlled Field Trial | To test the inconsistency between effectiveness of normative messaging in laboratory tests and boomerang effects observed in a few studies | Information provision;<br>Feedback;<br>Normative messaging | 5.7% for households with higher than avg. consumption;<br>8.6% increase for lower consuming households;<br>Adding an injunctive message | 287 househol ds | 8 weeks |
| The moderating role of individual differences in responses to benefit and temporal framing of messages promoting residential energy saving<br>Xu et al. (2015)<br>Randomized Contolled Trial in laboratory | To examine how framing of residential energy-saving benefits as benefit framing and temporal framing influenced attitudes toward and perceived outcome efficacy of energy-saving behaviors.<br>And to examine how individual differences in environmental concern, political orientation and consideration of future consequences (CFC) moderated message framing effects. | Framing:<br>Benefit (environment or economic)<br><br>Temporal (short-term or long-term) | Environmental framing led to more positive attitudes among political liberals alone.<br>Short-term economic framing led to more positive attitudes among low-CFC participants | 461 US residents | NA |
| Evidence From Two Large Field Experiments That Peer Comparison Feedback Can Reduce Residential Energy Usage<br>Ayres et al. (2009)<br>Two Randomized Controlled Field Experiments | To analyse the effect of providing feedback to customers on home electricity and natural gas usage with a focus on peer comparisons | Indirect feedback with Home Energy Reports;<br>Social norms | 1.2% (1st Experiment)<br>2.1% (2nd Experiment)<br>Savings sustained over the period | 40,000 househol ds<br>35,000 househol ds | 7 months;<br>12 months |
| Using social norm to promote energy conservation in a public building<br>Liu et al. (2016)<br>Randomized Controlled Field Experiment | To examine the impact of social norms on petition signing addressing energy consumption in a University campus building | Information provision;<br>Message Framing;<br>Social norms | 5% more students signed a petition | 1840 universit y students | 5 days |

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| Normative Social Influence is Underdetected<br>Nolan et al. (2008)<br>Randomized Controlled Field Experiment | To investigate the persuasive impact and detectability of normative social influence. | Framing: environmental, societal, monetary;<br>Social norms | 10.1% during the initial period and 7.2% effects after two months | 981 households | 2 months |
| Do Extrinsic Incentives Undermine Social Norms? Evidence from a Field Experiment in Energy Conservation<br>Pellerano et al. (2016) | To test whether the policy tools of prices and normative appeals are complements or substitutes. | Financial incentives;<br>Social norms | 1% for social comparison alone | 82602 households | 4 months |
| The importance of message framing for providing information about sustainability and environmental aspects of energy<br>Van de Velde et al. (2010)<br>Randomized Controlled Laboratory Survey | To test effects of a positive and negative framed message on people's concern related to energy and environmental problems;<br>And to investigate which socio-demographic characteristics will influence people's sensitivity for the message frame | Message framing | Men, higher educated people, people between 35 and 54 years old and people with the most pro-environmental attitude are less affected by the message frame, while the choice of the frame is more important when addressing women, people younger than 35 and older than 55 years, lower educated and less pro-environmental people. | 260 people | NA |
| Commitment and Behavior Change: Evidence from the Field<br>Baca-Motes et al. (2013)<br>Randomized Controlled Field Experiment | To test commitment, self-signaling, and the principle of consistency in a large, intensive field experiment examining the effect of hotel guests' commitment to practice environmentally friendly behavior | Information provision;<br>Private Commitment<br>Symbolic reinforcement with lapel pins | 40% increase in the number of towels hung over to be re-used | 2416 hotel guests | 31 days |
| Public commitment and energy conservation<br>Shippee & Gregory (1982)<br>Randomized Controlled Field Experiment | To evaluate comparatively the effectiveness of two community interventions designed to publicly commit commercial-industrial firms to energy conservation | Information provision;<br>Feedback;<br>Public Commitment | 30% savings for mild commitment;<br>1% increase in consumption for strong commitment | 16 small commercial-industrial firms | 4 months |
| Commitment and Voluntary Energy Conservation<br>Pallak & Cummings (1976)<br>Two Randomized Controlled Field Experiments | To access the relative impact of public and private commitment | Public and Private commitment<br>Indirect feedback<br>Information provision | 422 cubic feet of gas more saved for public commitment than for private commitment and control;<br>438 kWh electricity saved for public commitment | 65 households (Natural gas);<br><br>142 households | 29 days |

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| A social-psychological analysis of residential electricity consumption: the impact of minimal justification techniques<br>Katzev & Johnson (1983)<br>Randomized Controlled Field Experiment using Foot-in-the-door technique | To explore the impact of foot-in-the-door technique for inducing verbal compliance and behavioural compliance to conserve energy | Information provision: prompts to signal energy-saving actions;<br>Indirect feedback;<br>Financial incentives;<br>Goal setting | 4% - 10% compared to control<br>Foot-In-The-Door group has significantly more conservers than Control group.<br>All 3 treatment groups (Questionnaire only; Goal setting only; FITD) showed significant reduction w.r.t. baseline. | 66 homeowners | 5 months |
| Energy conservation through product-integrated feedback: The roles of goal-setting and social orientation<br>McCalley & Midden (2002)<br>Randomized Controlled Laboratory Experiment using Computer simulation | To explore the role of goals and feedback to save energy | Goal setting;<br>Social norms<br>Feedback | Self-set goal group used 21% less energy than the control group. Both self-set goal group and assigned goal group generated similar savings | 100 subjects | NA |
| Goal Setting and Feedback: The Programmable Thermostat as a Device to Support Conservation Behavior in the User<br>McCalley & Midden (2003)<br>Randomized Controlled Laboratory Experiment using Computer simulation | To test of the effects of goal and information specificity on planning a thermostat programming strategy. | Goal setting;<br>Specific Information provision; | Specific information led to setting of higher conservation goals | 100 subjects | NA |
| The Effect of Goal-Setting and Daily Electronic Feedback on In-Home Energy Use<br>van Houwelingen & van Raaij (1989)<br>Quasi-experiment with longitudinal study | To test that goal-setting and the use of Indicator about usage (plus conservation information) will reduce the use of natural gas for home heating | Goal setting;<br>Feedback with indicator about usage;<br>Information provision | 12.3% reduction in Natural gas use in the Indicator condition;<br>No significant savings 1 year later, in the absence of Indicator. | 325 households | 1 year |
| Goal setting and energy conservation<br>Harding & Hsiaw (2014)<br>Cohort study based on field data | To study consumers' decisions to join a conservation program and their subsequent behavior upon joining. | Information provision;<br>Goal setting: self-set goals<br>Feedback<br>Financial incentives | 4.4% average savings;<br>11% savings for informed customers who set realistic goals | 2487 adopters;<br>9964 Control households | 18 months |

## Appendix B: Survey Questions

Page1:

The National Environment Agency of Singapore has introduced **Green Tick** energy labelling for Refrigerators, Air Conditioners, Clothes Driers, TVs and Lamps


Q) Have you heard about the **Green Tick** energy labelling for electrical appliances before?

☐ YES ☐ NO ☐ NOT SURE

Page 2:

Upgrading an old refrigerator to a more efficient one can save you money!

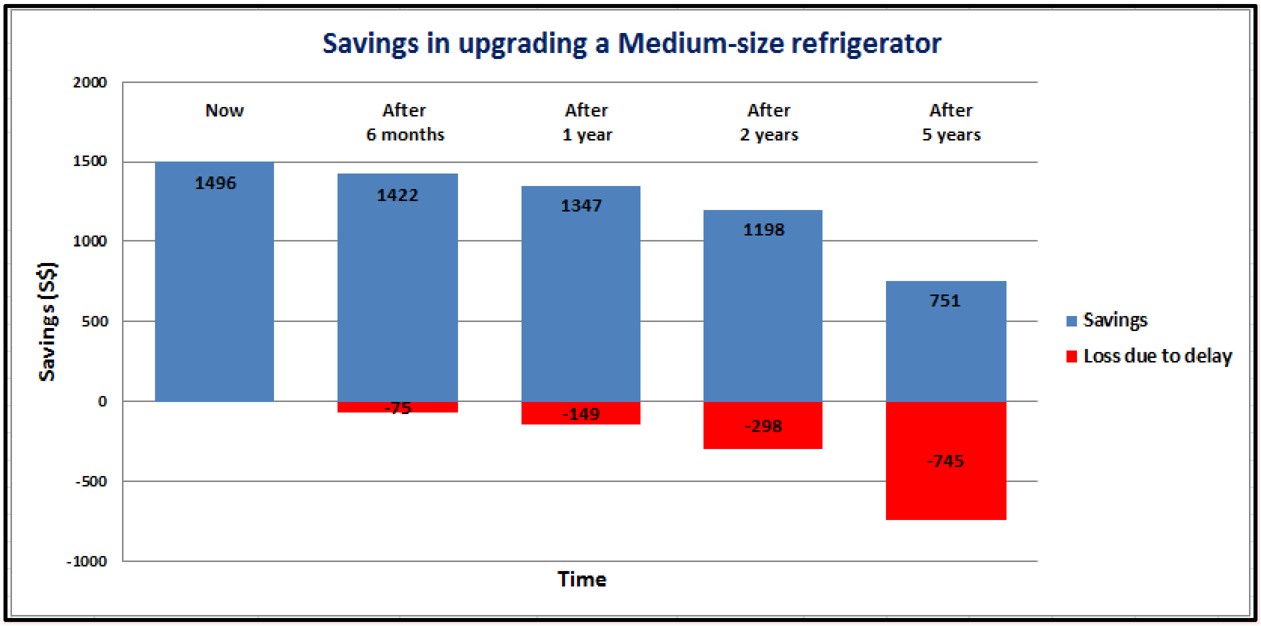
**Costs and savings in upgrading to an efficient refrigerator**

| Refrigerator | Small (250 ltr)  | Medium (330 ltr)  | Large (500 ltr)  |
|---|---|---|---|
| Energy Rating | ✓✓✓ | ✓✓✓ | ✓✓✓ |
| Purchase cost | S$518 | S$749 | S$1299 |
| Energy savings (life time) | S$1172 | S$ 1496 | S$ 1523 |
| Savings in 10 years | $ | $ $ | $ $ $ |

Q) What is the approximate size of your current refrigerator?

☐ SMALL (100-250 litres) ☐ MEDIUM (250-350 litres) ☐ LARGE (350-600 litres)

Page 2 A (Treatment):




**The longer you delay, the more electricity (and money) you are wasting!**

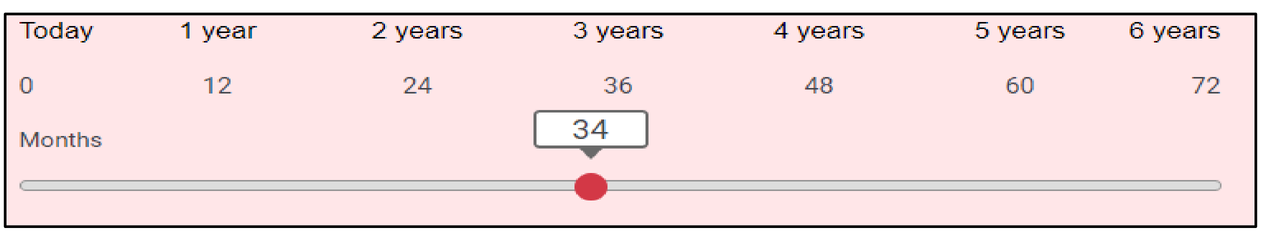
Page 3:

Q) Would you consider upgrading to an efficient refrigerator in the future?

☐ YES ☐ NO ☐ MAY BE

Page 4:

Q) HONESTLY, in how many months do you think you will replace it?



## Appendix C: Assumptions made in Life Cycle Cost calculations

- Refrigerator model: Top Freezer
- Lifetime of new fridge: 10 years
- Green ticks for old fridge: Zero
- Green ticks for new fridge: Three
- Residential Electricity Price=: $0.27/kWh
- Maintenance cost: Zero
- Disposal cost: Zero

| **Electricity consumption** | SMALL | MEDIUM | LARGE |
|---|---|---|---|
| OLD (0 ticks) | 708 kWh | 861 kWh | 962 kWh |
| NEW (3 ticks) | 274 kWh | 307 kWh | 398 kWh |

## Appendix D: The Pure Procrastination Scale

**Instructions**: Below are 12 statements which people may use to describe themselves. Read each statement and decide whether or not it describes you.

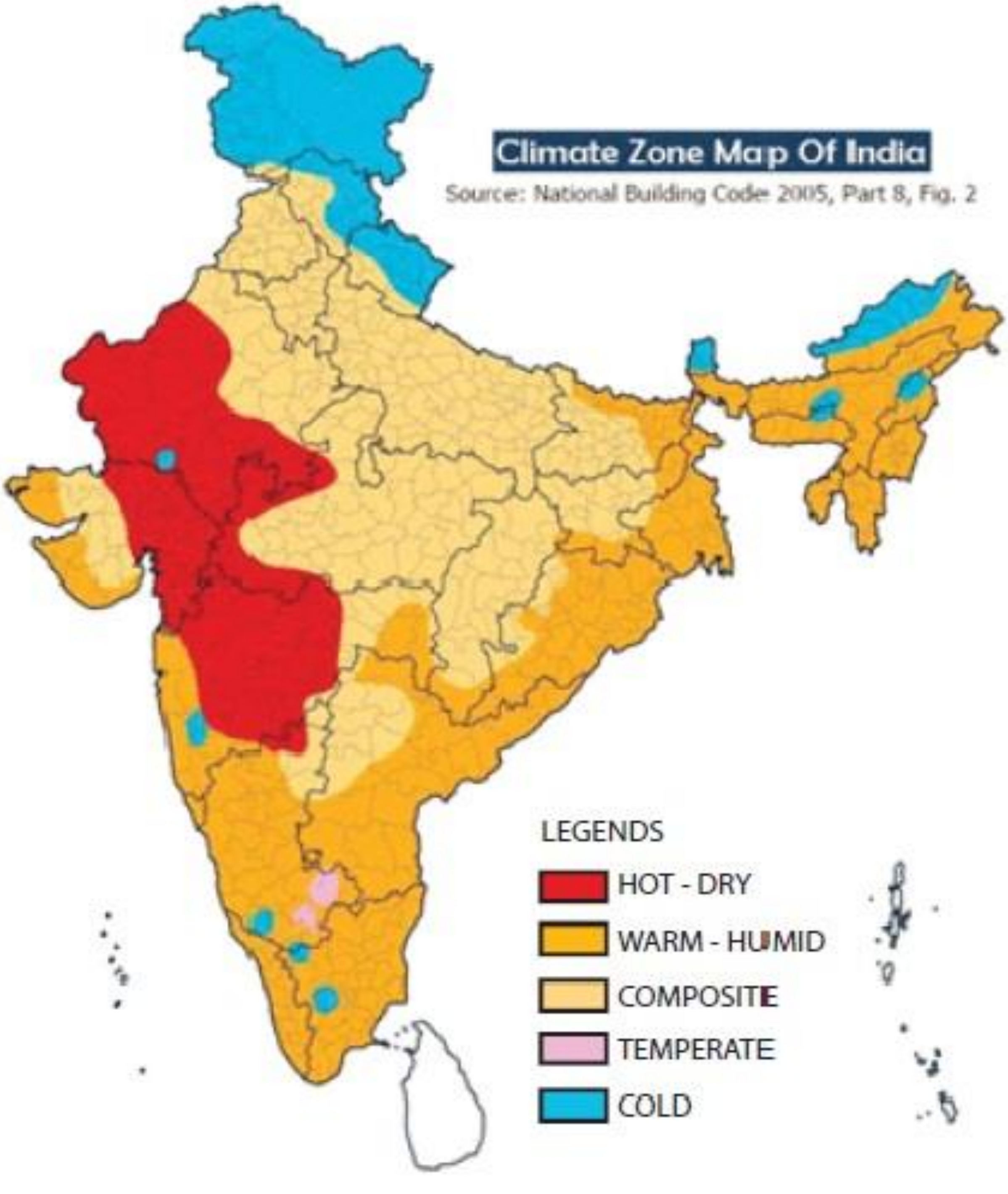
| Not like me At all | Not like me | Sometimes like me | Like me | Very much like me |
|---|---|---|---|---|
| 1 | 2 | 3 | 4 | 5 |

1. I delay making decisions until it's too late.
2. Even after I make a decision I delay acting upon it.
3. I waste a lot of time on trivial matters before getting to the final decisions.
4. In preparation for some deadlines, I often waste time by doing other things.
5. Even jobs that require little else except sitting down and doing them, I find that they seldom get done for days.
6. I often find myself performing tasks that I had intended to do days before.
7. I am continually saying “I'll do it tomorrow”.
8. I generally delay before starting on work I have to do.
9. I find myself running out of time.
10. I don't get things done on time.
11. I am not very good at meeting deadlines.
12. Putting things off till the last minute has cost me money in the past.

## Appendix E: Embodied Energy for a Typical Residential Building

| Item and Materials | Quantity | Unit | EE value | Total EE |
|---|---|---|---|---|
| **Foundation including plinth** | | | | |
| 1:4:8 Cement Concrete bed | 9.73 | Cu.m | 783 | 7623 |
| RR masonry in CM 1:6 | 45.04 | Cu.m | 478 | 21540 |
| Concrete in plinth beam | 1.9 | Cu.m | 1350 | 2565 |
| Steel in plinth beam | 109 | Kg | 32 | 3520 |
| **Wall and supporting structure** | | | | |
| Brickwork in CM 1:6 | 85.51 | Cu.m | 2426 | 207473 |
| Concrete in lintel, sunshade and slabs | 4.76 | Cu.m | 1350 | 6426 |
| Steel in lintel, sunshade and slabs | 373.42 | Kg | 32 | 11961 |
| **Floor and roof** | | | | |
| Concrete in roof slab | 24.73 | Cu.m | 1350 | 33387 |
| Flooring concrete 1:5:10 | 3.8 | Cu.m | 679 | 2580 |
| Steel in roof slab | 1941.31 | Kg | 32 | 62180 |
| **Doors and Windows** | | | | |
| Doors | 25.03 | Sq.m | 0 | 0 |
| Windows | 39.57 | Sq.m | 0 | 0 |
| Iron in doors and windows | 39.26 | Kg | 32 | 1257 |
| **Finishes** | | | | |
| Ceiling plastering in CM 1:3 | 231.68 | Sq.m | 25 | 5850 |
| Wall plastering in CM 1:6 | 761 | Sq.m | 17 | 13173 |
| Floor finishing with ceramic tiles | 190.84 | Sq.m | 203 | 38697 |
| **Painting** | | | | |
| Emulsion paint for walls and ceiling | 749 | Sq.m | 16 | 11684 |
| Enamel painting for doors & windows | 139.6 | Sq.m | 16 | 2178 |
| **Miscellaneous - Staircase** | | | | |
| Concrete | 1.4 | Cu.m | 1350 | 1890 |
| Steel | 109.9 | Kg | 32 | 3520 |
| | | | | |
| **Total Embodied Energy in MJ** | | | | 437504 |
| | | | | |
| **Built-up area** | 202 | Sq.m | | |
| **Energy intensity per unit floor area** | | **MJ/Sq.m** | | **2167** |

## Appendix F: Climate Zone Map of India



## Appendix G: Salient Features of National Building Code (2016)

I. Detailed provision for streamlining the approval process in respect of different agencies in the form of an integrated approval process through single window approach thereby avoiding separate clearances from various authorities, with a view to ensuring ease of doing business in built environment sector.
II. Progressive computerization of approval process, for enabling online submission of plans, drawings and other details, and sanction thereof.
III. Updated mechanism of ensuring certification of structural safety of buildings by the competent professional and peer review of design of buildings.
IV. Defining the roles and responsibilities of all professionals and contractors involved in a building construction project.
V. Comprehensive planning norms for minimum amenities to be provided in a city/town.
VI. Detailed provisions relating to requirements for accessibility in buildings and built environment for persons with disabilities and the elderly.
VII. Planning and development norms, such as, Transferable Development Rights (TDR) and Accommodation Reservation (AR).
VIII. Provisions for underground or multi-storeyed parking as also mechanized parking of vehicles.
IX. Norms for solar energy utilization.
X. Requirements for buildings on podium for ensuring fire and life safety in such buildings.
XI. Fire and life safety in modern complex buildings including the high rises, glazed buildings, atria, commercial kitchen and car parking facilities.
XII. Updated structural design provisions for wind and seismic loads, imposed load due to helipad, and blast loads, for safe design and construction of buildings with due focus on ductile detailing.
XIII. Latest research and development inputs and provisions on concrete, steel and masonry buildings with a view to ensuring disaster resilient buildings.
XIV. Assessment of liquefaction potential of a site and ground improvement techniques for maximum utilization of land resources including at seismically vulnerable sites.
XV. Updated provisions on engineered use of bamboo in housing and other building construction.
XVI. Promotion of use of agricultural and industrial wastes including construction and demolition wastes in building construction without compromising the quality and safety.

XVII. Inclusion of provisions on self compacting concrete, high performance concrete and steel fibre reinforced concrete.

XVIII. Updated provisions on prefabricated construction technique for speedier construction.

XIX. New chapter on structural use of glass in buildings.

XX. New and alternative building materials, and technologies for building construction such as, reinforced masonry, confined masonry building construction and masonry wall construction using rat-trap bond.

XXI. Construction project management guidelines for timely completion of building projects within the budgeted cost with desired quality.

XXII. Habitat and other welfare requirements for workers at construction site.

XXIII. Inclusion of modern lighting techniques such as LED and induction light and their energy consumption.

XXIV. New provisions on compact substations and updated provisions on installation of energy meters.

XXV. Comprehensive provisions relating to lightning protection of buildings.

XXVI. Provisions on aviation obstacle lights; electric vehicle charging and car park management.

XXVII. Protection of human beings from electrical hazards and against fire in the building due to leakage current.

XXVIII. Use of refrigerants for air conditioning addressing zero ozone depletion potential (ODP) and ultra-low global warming potential (GWP).

XXIX. Inclusion of new and energy efficient options of air conditioning, heating and mechanical ventilation, such as variable refrigerant flow system, inverter technology, district cooling system, hybrid central plant using chilled beams, radiant floor components, and geo-thermal cooling and heating.

XXX. Thrust on envelope optimization using energy modelling, day lighting simulation, solar shade analysis and wind modelling software to optimize the air conditioning load.

XXXI. Air conditioning, heating, and ventilation (HVAC) provisions considering adaptive thermal comfort conditions for energy efficiency.

XXXII. Provisions pertaining to metro trainways and metro stations with respect to fire and life safety; and air conditioning, heating and ventilation for metro stations.

XXXIII. HVAC requirements for data centres and healthcare facilities; refrigeration for cold stores; efficient strategies for winter heating using reverse cycle operation, solar heating systems, ground source heat pump and electric heat pump; and modern system of mechanical ventilation for industries, commercial kitchen and underground car parking.

XXXIV. Updated provisions on building automation system to include the latest practices for web-based monitoring and control of performance parameters.

XXXV. High speed lifts for tall buildings.

XXXVI. New chapter on escalators and moving walks for comfortable and safe movement of people.

XXXVII. New chapter on information and communication enabled installations in buildings.

XXXVIII. Updated provisions on water supply, drainage and sanitation for modern high-rise buildings and complexes.

XXXIX. Provisions relating to swimming pools covering hygiene and safety.

XL. Updated provisions on rainwater harvesting.

XLI. New chapter on solid waste management covering various solid waste management systems within the building and building complexes.

XLII. Updated provisions on piped gas supply in houses, and in hospitals for medical purposes.

XLIII. Promoting quality of outdoor built environment through updated provisions on landscape planning, design and development.

XLIV. Promoting sustainability in buildings and built environment in tandem with relevant sustainable development goals.

XLV. New chapter on asset and facility management to cover provisions relating to management of building assets and associated services, also covering responsibilities of occupants for maintenance of facilities, such as structures, equipment and exterior property.

## Appendix H: Brief comparison of LEED-India and GRIHA building rating systems

| LEED-India | GRIHA |
|---|---|
| **Site selection** | |
| Preference given to "brown-field" sites over "green-field" sites | More importance on the preservation of top soil and its fertility until post-construction |
| Buildings are recommended to be sited near to mass transit and transport amenities. Sharing of parking and fueling stations are recommended | |
| **Planning, Design, Construction and Operation** | |
| Natural ventilation systems need to meet "Good practices guide" of Carbon Trust | Quality of water need to comply with local codes and BIS standards |
| Permanent monitoring of $CO_2$ in ventilated spaces | Defined maximum levels for outdoor and indoor noise |
| Prevention of air quality loss due to construction activities | |
| Lighting controls in common spaces | |
| Indoor thermal comfort based on ASHRAE 55-2004 standards | |
| **Building materials and resources** | |
| Recommends use of certified wood products | Recommends products with low embodied energy and recycled products from industrial waste |
| Recommends rapidly renewably materials over those with longer replenishing rates | Recommends use of fly-ash |
| **Waste Management** | |
| Reduction of disposal to landfills. Recommends diversion of waste to manufacturing processes | Recommends treatment of water to meet disposal standards |
| **Energy Audit** | |
| Recommends a Monitoring and Verification plan that tracks and evaluates the actual performance with that defined in the design | Recommends monitoring of thermal performance and visual comfort |

| Additional Criteria | |
|---|---|
| Encourage installation in off-site renewable energy projects to compensate for on-site energy use | Proposes education and awareness campaigns to the building owners and occupants |
| Recommends elimination of building components that pose a risk of contamination | Recommends proper maintenance of electrical and mechanical systems |
| Recommends maintenance of existing building structures and to reuse them | Recommends a company policy for green supply chains |
| Recommends education of all project stakeholders on the LEED rating system, very early in the life of the project. | Recommends an integrated pest management plan to manage pests and weeds within tolerable limits |
| Recommends strategies to exceed a LEED-NC performance through energy-efficiency and water-efficiency measures | Recommends an extensive lifecycle cost analysis of the project, considering all the phases of the building lifecycle |