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Epistemological conflict: modern and non-modern frameworks for sustainability

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A basic epistemological conflict is found to exist between modern and non-modern practitioners of sustainable development. These categories distinguish the ways professionals interpret or frame reality. The hypothesis developed is that this inconsistency, at least partially, explains the limited success that energy-efficiency research has realized in the prediction and control of climate change catalysed by the built environment. An analysis employs both historical and empirical methods to understand how the North American air-conditioning industry has framed, and subsequently regulated, the inseparable problems of human comfort and energy consumption. Historically, the dominant framework long-inhabited by moderns has constructed a unit-efficiency model of evaluation that is concerned with universal standardization and normal design. In the empirical analysis of the selected case, an emergent framework inhabited by non-moderns constructed a unit-efficacy model of evaluation concerned with local implementation and post-normal design. The two models came into conflict when designers applied code-required energy models and financing formulae based on unit-efficiency assumptions to a case of sustainable, affordable housing. The analysis concludes with seven findings designed to move building energy research and practice beyond the current epistemological divide.

Keywords: buildings, building regulations, codes, efficacy, efficiency, frame analysis, governance, modelling, standardization, standards

Introduction

This analysis was provoked by a recent, real-world epistemological conflict – a dispute about how we know what we say we know. At times, epistemological conflict pits one isolated social group against another – as has historically been the case with tribes or religious sects. However, in diverse Western societies conflict is typically found between social groups loosely bound together by common frames of interpreting reality. Common frames of interpretation occur in specific contexts, sometimes for only a short period of time. In other words, individuals may inhabit different frames of interpretation in different contexts – at work, at home, in public or at a sporting event.

The field of ‘frame analysis’ was initially developed by sociologist Irving Goffman (Goffman, 1974) and was subsequently applied to the broad field of science and technology studies by Wiebe Bijker (Bijker & Bijsterveld, 2000) and others (Guy & Farmer, 2001). Most recently frame analysis was linked to questions concerning architectural judgment by Moore and Wilson (2013). These sources generally agree that frames help individuals not only to make sense of what is going on around them, but also to guide their actions. But, individual frames of interpretation are not synonymous with values. Rather, frames of interpreting phenomena both precede and inform the development of values, which Goffman likens to a ‘framework’ or ‘cosmology of frames’ (Goffman, 1974, p. 22) that are shared by social groups. Nor should frames be envisioned as interchangeable lenses through which people can seek to see things more clearly. Rather, they are overlapping three-dimensional spaces that people are trained by nested social groups to inhabit. Although frames are typically tacit, new frames of interpretation can be consciously adopted by individuals in action – when experience demonstrates to individuals how they may benefit by alternative interpretations of what is going on around them (Snow, Burke Rochford, Worden, & Benford, 1986).

On one side of the epistemological conflict examined in this paper is the long-established, and still dominant,
modern frame. The literature of modernization theory generally characterizes this way of interpreting the world as being concerned with universal standardization and normal design derived from the epistemological assumptions also embodied in the scientific method (Bidwell, 2009; Funtowicz & Ravetz, 1993; Jensena & Gram-Hanssena, 2008; Misa, Brey, & Feenberg, 2003; Scott, 1998; Mol, 2001). This frame has historically been inhabited and dominated by scientists and engineers. But, as history and the case studied below demonstrate, over time code-makers, energy-modellers, mortgage-lenders, property (real estate) developers, utility managers and some architects also found this frame to benefit their interests. In the world of building construction investigated herein, one self-described project of these modern practitioners has been to measure and control the peak energy loads in buildings which mechanical equipment can sustain to meet specified conditions. To satisfy this goal, inhabitants of the modern frame constructed a unit-efficiency model of analysis and production.

On the other side of the epistemological conflict analysed below is the emergent non-modern frame. This term derives from Latour (1993) who holds that, in practice, ‘we have never been modern’, if by that term we mean that universal standards actually exist outside of our minds, or are even possible. A non-modern frame is, then, characterized as being concerned not with universal standardization and normal design, but with local implementation and post-normal design (Bidwell, 2009; Leatherbarrow, 2005 [2010]; Svec, Berkebile, & Todd, 2012). This frame is typically inhabited and dominated by designers. But, as history and the selected case demonstrate once again, the non-modern frame has also become inhabited by politicians, activists and some scientists and engineers. In the world of building construction investigated herein, one self-described project of non-moderns has been to combat climate change – a post-normal condition – by first measuring, and then reducing, the consumption of fossil fuels, and thus the production of carbon, by the municipal ecosystem. To satisfy this goal, inhabitants of the non-modern frame constructed a unit-efficacy model of analysis and production.1

To make this distinction between efficiency and efficacy clear, the term ‘efficacy’ refers to the capacity of an agent to produce a desired effect – which, in the context of climate change, would be to reduce the consumption of fossil fuels, thus reducing carbon emissions, and mitigating climate change. In lieu of measuring overall effect on the system, however, the calculations made in the modern frame measure the relative energy-efficiency of particular technological devices, or units within the system. Efficiency is, of course, only a ratio of output to input (Moore, 2014) and is not a measure of effect. The conceptual model, or paradigm, initially developed by engineers at the turn of the 20th century, and still in use today by moderns, measures the ability of units within the system to meet peak demand, or load, not the overall energy consumption of the system over time. The argument made herein is that measuring system-efficacy and measuring unit-efficiency are fundamentally different concepts. It is this epistemological conflict concerning what is measured, and therefore managed, that leads to ineffective decision-making in the effort to achieve sustainable development.

The analysis is presented in two parts. In the first, or historical, section of the paper, the hypothesis developed argues that in our current situation the modern frame lacks internal validity, if the goal is to foster sustainable development as defined by the Brundtland Commission (WCED, 1987). This is to say that modern computer models generally required by governmental and institutional codes to measure compliance with the broad goals of sustainable development do not measure system-wide energy efficacy under the real-world dynamic conditions of open systems. Rather, they measure only the thin thermodynamic efficiency of units within a theoretically closed system under static, or steady-state conditions.2 In the second, or empirical, section of the paper, a case of affordable/sustainable housing in Austin, Texas, is examined. Here the problem at hand was defined by non-modern actors (who authored the City’s 2020 Climate Protection Plan – CPP), not by using the historically modern unit-efficiency model of evaluation, but by developing a new system-efficacy model suggested by the Brundtland Report (WCED, 1987). In this context, the pursuit of system efficacy means that the non-modern community was concerned not with the relative thermodynamic efficiency of various technological pieces, but with system- or city-wide consumption of fossil fuels. Behind this shift in focus was a concern with the general consequences of climate change, and a specific concern for negative consequences on the most vulnerable populations in the city. When the non-modern system-efficacy model was applied to a case of affordable housing in Austin, conflict emerged because the energy-modelling software and corresponding codes mandated by federal, state and local codes, as well as financing institutions, was derived from the modern unit-efficiency model developed a century earlier. By failing to recognize context-dependent variables in the city-wide system, design decisions were restricted by modern codes and energy modelling software to abstract building-scale equipment trade-offs that ignored system-wide opportunities that may have better satisfied the explicit goals of sustainable development articulated by citizens.

**Historical analysis**

The field of Science and Technology Studies, sometimes referred to as Science, Technology and
Society (STS), has demonstrated countless times over the past five or six decades that technological change both reflects and catalyses social change (Hess, 1997; Kuhn, 1962; Latour, 1987; MacKenzie & Wajcman, 1999; Moore, 2001; Moore & Karvonen, 2007; Sismondo, 2010; Smith & Marx, 1994). This is to say that in order to understand why technologies take the form they do, it is also necessary to understand the social interests that drive them and, in turn, derive from them. In this complex and layered case of contemporary building codes, energy-modelling software and financing formulae, it is necessary to provide historical context to inform the empirical case study that follows.

Social construction of the air-conditioning industry

In her seminal book Air-Conditioning America: Engineers and the Controlled Environment, 1900–1960 (1998), Gail Cooper documents how modern air-conditioning initially developed out of a conflict between 19th-century master-weavers, their bosses and a new class of engineer-managers who sought to expand their own interests. The path of developing this new refrigeration machinery intersected the development of dissection theatres in medical schools, the palaces of the nouveau riche, the New York Stock Exchange and the halls of silent movies, long before what is today called ‘air-conditioning’ became a North American standard for achieving human comfort. Cooper (1998) conveys an understanding that the development of ‘AC’ was never linear, or a process predetermined by a superior scientific logic now embedded in the compressors humming in the side-yard of suburban homes. Rather, what is often assumed by many to be technologically inevitable is a social construct that might have turned out differently. The history reconstructed by Cooper and others are ‘technological dramas’ (Pfaffenberger, 1992) in the contested development of space conditioned by machines rather than architecture per se. This analysis of the co-construction of building codes, energy-modelling software and financing institutions can be understood as the documentation of another technological drama in the genre pioneered by Cooper and others.3

Defining the problem at hand

What gets done, in almost any society, is largely determined by who gets to define, or frame the problem at hand (Benhabib, 1996; Latour, 2004). At the turn of the 20th century the once-united disciplines of architecture and engineering were in the final throes of professional ‘estrangement’ (Peters, 1993) and in competition to frame society’s problems (Brain, 1991). The new concept of creating human comfort, not by the manipulation of architectural variables (roofs, walls and windows), but by environmental variables (temperature and humidity), presented to engineers (heating, ventilating and air-conditioning, or HVAC, engineers in the United States, and building service engineers in the European Union) the opportunity for market differentiation (Nye, 2006). How these technologies and practices were framed differently in North America and Europe had to do not only with different bio-climates, but also with the pre-existence of different building cultures (Davis, 2006). This is to say that the invention of air-conditioning technologies is inseparable from the invention of engineering as a social practice in a particular social and environmental context. Moderns in North America, then, framed the problem of space conditioning somewhat differently than did their European, Asian or African counterparts.

At the turn of the 20th century, air-conditioning design for industrial buildings in North America, such as textile manufacturing noted above, was more of an ‘art than a science’ (Tull, 1971). Yet, as Cooper (1998) documents, engineers could see that by reframing a labour problem, which they could not control, to be a thermodynamic one, which they could, their services became far more valuable (Cooper, 1998). A thermodynamic problem is, of course, a highly complex set of interacting phenomenon requiring the use of dynamic equations based on the principles of heat transfer and fluid dynamics. The constantly changing position of the sun, the thermal storage properties of building materials, the complexities of air movement and external energy exchanges to the wider environment all need to be considered simultaneously in order confidently to predict indoor environmental conditions. One way that early analysts dramatically simplified this calculation, then done by human calculation (i.e. not computer software), was to limit the system boundary to the building envelope (including solar radiation). A second simplification was to assume static, or normal, operating conditions. These habits continue to this day, even though modern analysts are generally aware that this practice is grossly simplistic, or shallow.4

By the end of the 19th century, the most sophisticated method of calculating peak loads was Alfred Wolff’s heat-unit method. Wolff, a German engineer, came to recognize that controlling indoor climate was not only a thermodynamic calculation. Rather, both architectural conditions (how the building is constructed) and social conditions (how people behave inside buildings) influence the effectiveness of the mechanical system (Wolff, 1894). Unhappy clients were evidence that engineers of the time were unable to predict how buildings would be actually constructed and used. In other words, in order to be able to design and predict the exact conditions required by modern industry, engineers of the late 19th century had two theoretical alternatives:
• develop a comprehensive method of calculation that could account for thermodynamic, architectural and social variables inside the building (which was then impossible) or

• develop a method of calculating thermodynamic variables (which was possible) and then prescribe to owners the architectural and social variables required for the system to work as they predicted.

The ability to do the latter was made possible by Willis Carrier’s development of psychrometrics between 1902 and 1911. This is to say that it was rational, and in the interest of engineers, to freeze-frame the problem definition to the time of design of the system so that the messy variables of actual construction and inhabitation would not constitute a liability (Cooper, 1998).

Moderns were, at least initially, successful in reframing the problem at hand as a shallow thermodynamic one. Stated in reverse, because engineers were developing the skills to control thermodynamic conditions in enclosed spaces, they were able to create a new profession, a new industry and a new way of life (Winner, 1977). It was their success in barring non-thermodynamic variables from design consideration that foreshadows the post-normal conflict embodied in the case to be considered below.

Unit-efficiency model of evaluation
As does any culture of praxis, modern engineering culture has a number of foundational values (Bourdieu, 1993). One of these, as Simon, Langley, and Bradshaw (1981, p. 2) recount it, is that ‘Solving complex problems generally involves decomposing them into sets of simpler problems and attacking these’. Simon et al. go on to argue that the modern directive to ‘decompose’ problems is a highly problematic one. Another way to say this is that the complex, or ‘wicked problems’ (Rittel & Webber, 1973), found in society are larger than the sum of their parts. Atomizing problems into smaller units within the system of which they are a part, or reframing the system boundaries, tends to mask the existence of key causal relationships in the system.

Systems analyst James J. Kay (1922, cited in Moe, 2014b) has summarized this theoretical problem in a way that is directly related to the case studied below. He holds:

any time one part of a system is optimized in isolation, another part will be moved farther from its optimum in order to accommodate the change. Generally, when a system is optimal, its components are themselves run in a suboptimal way. One cannot assume that imposing efficiency on every component in a system will lead to the most efficient system overall. (Kay, 1922, p. 147, cited in Moe, 2014b, p. 155, emphasis added)

What Simon et al. (1981), Rittel and Webber (1973), and Kay (1922, cited in Moe, 2014b) help to elucidate that improving the efficiency of any one unit, or even all units, within a system may produce perverse results, if design decision-makers are genuinely interested in the sustainable operation of the whole system and not simply the unit for which they are responsible.

In the case of early air-conditioning noted above, the primary problem was, for moderns, to limit the definition of the problem to the thermodynamic variables that they could control within a building envelope owned and controlled by a specific client. If the problem is only to provide specified interior environmental conditions, then calculating peaks loads would suffice because all lesser conditions would also be met. If one accepts the modern frame of interpreting buildings as an isolated, closed system, this is perfectly coherent reasoning. It did, however, contribute to a culture of over-sizing equipment to avoid liability (Lokmanhekim, 1971) – a practice still common in the industry today, and one based on the original problem frame.3

A metaphor drawn from the automotive industry may make the distinction between calculating peak load and calculating consumption clearer. Given the US interstate highway code that mandates a maximum speed of 75 mph and a minimum speed of 45 mph, designers can choose (1) to build a machine that will reach the maximum speed very quickly, and thus satisfy the driver’s short-term interests by getting up to speed very fast. Less time is consumed. Or, designers can choose (2) to build a machine that will reach maximum speed slowly and thus satisfy the driver’s long-term interests. In other words, sports cars are designed for quick acceleration and high top-speeds. These criteria require the work of accelerating the vehicle’s mass and overcoming friction and air resistance to be performed at a rapid rate. Therefore, sports cars’ engines are optimized for high power output. The necessary trade-off is that under normal driving conditions they do not operate efficiently from the standpoint of distance travelled per volume of fuel consumption. Cars with petrol (gasoline) engines designed for fuel economy, on the other hand, have engines optimized to carry the driver as far as possible while consuming little fuel. Such cars excel in fuel efficiency by transporting the driver with a minimum of energy consumed, but are clearly inferior to the sports car if the criterion is time efficiency in reaching highway speed or one’s destination on the motorway. Building HVAC systems work...
similarly. When these systems are sized for extreme peaks, they will satisfy these conditions quickly, but will not operate as energy efficiently under normal conditions as a system that runs close to capacity for longer periods. Which is the more rational technological choice is a matter of how designers frame, or interpret, ecological and social context, not mathematics.

To put this all in an even broader social context, historian Howard Davis has defined ‘building culture’ to be ‘the coordinated system of knowledge, rules, procedures, and habits that surround the building process in any given place and time’ (Davis, 2006, p. 5). This historical analysis demonstrates, then, that the modern building culture of air-conditioning was constructed (1) to define and atomize the problem at hand as thinly thermodynamic, (2) to limit the thermodynamic boundary of the system to the building envelope, (3) to measure the problem in terms of peak load capacity, not energy consumption, and (4) to avoid conflict in the market. By the late 20th century this modern building culture was able to ‘align’ (Snow et al., 1986) its ‘system of knowledge, rules, procedures and habits’ with competitors (i.e. architects) and thus dominate the construction industry. As it did, two key advances were necessary: (1) a more efficient or faster way to calculate peak loads (i.e. computers), and (2) a professional organization that would normalize modern industry-wide standards.

Rationalizing the unit-efficiency model in practice
Cooper (1998) documents how framing the problems of manufacturers as thinly thermodynamic was quickly transferred to other building types. Simply put, workers in and visitors to early industrial installations discovered that cooler temperatures were desirable for other kinds of social activities. But more important was what can be called the simultaneous co-construction or collaborative reframing of building codes, energy models and mortgage financing formulae that were necessary to normalize the unit-efficiency model. In this short article it is impossible to tell such a complex story in full. It is possible, however, briefly to tell the story of the ‘Post Office Program’ as a particularly important chapter in the normalization and reproduction of the modern unit-efficiency model. Historical analysis demonstrates how this computer program, and its derivatives, has influenced not just cooling load calculations, but also other sectors of the economy that influence system efficacy, one example being the mortgage industry.

One of the first engineers to recognize the possibilities for dynamic thermal analysis using computers was T. Kusuda. Having worked with the air-conditioning manufacturer Worthington – a pioneer in computation methods (Soumerai, Kusuda, & Difitach, 1959) – he joined the National Bureau of Standards (NBS) in 1962, a critical time when NBS was commissioned by the Department of Defense to investigate the use of air-conditioning in civilian bomb shelters. Kusuda recognized that given highly variable soil temperatures at shallow depths, the only practical way to calculate loads would require more advanced computational methods offered by computers (Kusuda, 1977). The advances made at NBS by the mid-1960s commanded the attention of engineers in industry, particularly those affiliated with the American Society of Heating, Refrigeration and Air-conditioning Engineers (ASHRAE, and its previous incarnations). ASHRAE had, up until this point in time, provided the industry standards for the manual calculation methods for heating and cooling loads. Realizing that their methods, and thus their influence in the building culture, were becoming outdated by emergence of the computer, ASHRAE established the Task Group Energy Requirements (TGER) to standardize computer calculation methods in order to determine peak heating and cooling loads in commercial buildings (Tull, 1971; Kusuda, 2001).

The US Postal Service (USPS) was one of the first organizations to develop a software package based on ASHRAE’s and TGER’s new digital procedures. Referred to as the Post Office Program, its primary purpose was to assist in life cycle cost assessments of the organization’s many building projects across the country (Lokmanhekim, 1971). What is so significant about the Post Office Program is that its three conceptual components – peak load calculation, systems design and economic analysis – have endured as the basic method still employed in contemporary energy models. These conceptual frames provide modern analysts with a process to isolate various units of a building assembly, and thus determine their ability to meet peak energy loads (Tull, 1971). The Post Office Program was the state-of-the-art tool related to energy use available at the time of the 1973 oil crisis catalysed by the Organization of the Petroleum Exporting Countries (OPEC). This event brought to public awareness the inherent problem of framing systems to be closed thermodynamic or closed political ones, when in reality they are inherently linked. Those modern epistemological assumptions were that (1) system analysis could be frozen, or framed to be conditions known only at the time of design, and (2) calculations could be limited to peak loads required only within the building envelope.

First challenge to the unit-efficiency model
In the wake of the OPEC oil embargo, and new concerns about the porous boundaries that exist between systems of space conditioning and national security, Congress passed the Energy Policy and Conservation Act of 1975, which required states to adopt energy codes regulating the use of energy in buildings. Soon
thereafter, and at the recommendation of the NBS, the air-conditioning industry itself, under the direction of ASHRAE, was commissioned to author an enforceable consensus-based standard. ASHRAE, realizing the significance of this task, not only for the country, but also as a means for ASHRAE’s corporate affiliates to influence national energy policy (Busch, 2011), agreed to write the standard. The result was ASHRAE 90-75 and it represented the first codified national energy standard (Kirkwood, 2010). Its significance is not only that it was a regulatory first, but also that it reframed the problem from the regulation of peak loads to the regulation of consumption. In other words, ASHRAE 90-75 reframed the problem definition, if not the methods of calculation.

The California Energy Commission, with the assistance of the federal Energy Research and Development Administration (ERDA — which would eventually be renamed the Department of Energy, or DOE), enhanced the Post Office Program to develop a state code in compliance with ASHRAE 90-75 (Haberl & Cho, 2004). This tool, named Cal-ERDA, was not only used to develop the code, but also was made publicly available to practitioners and municipalities to demonstrate compliance with the code. With additional support of the Lawrence Livermore Laboratories at the University of California, Cal-ERDA would be updated and rolled into a DOE-sponsored research project to develop a software tool specifically for code development. Later renamed DOE-2, the software would become the preeminent energy modelling calculation engine and is still in use today (Haberl & Cho, 2004). DOE-2 is also the main component of EnergyGage USA, the software used to model the energy performance in the Austin case studied below.

It is hard to overstate the influence of energy modelling software in the development of contemporary energy codes. From the first instance, energy modelling software was inextricably linked to, or co-constructed with, energy regulation. However, the basic research used to develop the algorithms of the software was based on the modern science of predicting unit efficiency (heating and cooling peak loads for mechanical equipment), not for measuring non-modern system efficacy (system-wide energy consumption).

Second challenge to the unit-efficiency model

Although the OPEC embargo of 1973 was the first public challenge to using peak load calculations as the primary criteria for design, it was the slow acknowledgement of climate change, its causes and consequences that has reframed design criteria to be almost exclusively concerned with system-wide consumption, not unit efficiency. In the popular imagination of the time, however, these concepts were synonymous. By the turn of the 21st century energy conservation was becoming an aspiration, even to those who were initially sceptical. A good example of this shift is the emergence of the Residential Energy Services Network (ResNet), a not-for-profit arm of the mortgage industry. In 1995 ResNet constructed a residential energy efficiency standard for mortgage lenders, known as a HERS rating, based on the International Energy Conservation Code (IECC), developed subsequent to ASHRAE 90.1 (ResNet, 2007; ResNet, 2014). Significant for the real estate development and mortgage industries is that studies that have occasionally supported the common assumption that energy-efficient HVAC systems increase the value of property for owners (Porteous, 1997). Other studies have, however, questioned if renters will actually pay more for energy-efficient real estate (Gabe & Rehm, 2014). Although the research may not yet be definitive, it is clear that some lenders and developers have consciously aligned their investment interests with the advocates of modern unit efficiency, if not with the non-modern advocates of system efficacy.

When fundamentally conservative economic actors, like real estate developers and lenders who are reluctant to invest without a perceived return, begin to adopt new standards like energy conservation, it suggests that the building culture as a whole – ‘the coordinated system of knowledge, rules, procedures, and habits that surround the building process’ (Davis, 2006, p. 5) – has shifted, or been reframed to be modern. The recent solidification of the interests and practices of code-makers, energy-modellers and financial lenders is but one very important example. The constant reconstruction of social values, however, tends to outpace the reconstruction of modes of calculation built on a century of practice because modern culture as a whole considers mathematical calculation to be value or frame free.

A brief discussion of a classical STS analysis by Bowker and Star (1994), from another professional field – public health – will help illustrate the obduracy and authority of numbers in the modern frame. In their study of the International Classification of Diseases (ICD), which is the ‘decision-making tool’ used by the World Health Organization (WHO) to direct world health policy, the authors found that data inputs into the universal system were inevitably reframed, or interpreted by, practitioners through local interpretive norms held by members of specific social groups. Their research seriously challenged the validity of WHO’s seemingly objective data in several ways. The authors argued that:

first, there is a permanent tension between attempts at universal standardization of lists, and the local circumstances of those using them; [and] second, this tension should not, and cannot, be resolved by imposed standardization, because the problem is recursive [ . . . ].

(p. 190)
Put simply, Bowker and Star demonstrate that the categories into which modern, context-free data are put are socially constructed, dynamic over time and mean different things to different social groups, no matter how rigorously they are defined by the authors of the decision-making tool. Whether one is counting variations of disease morbidity or variations of peak energy loads in buildings, the argument remains the same. ‘It is unrealistic and counter-productive to try to destroy all uncertainty and ambiguity in these sorts of infrastructure tools’ (p. 208). The advice of these and other STS practitioners is that the energy research community would be more successful in achieving stated goals by examining the social construction of frames of interpretation embedded in modern decision-making tools, like energy models, than in honing the mathematics.

In sum, this historical analysis demonstrates that buildings, building codes, building energy-modelling software, the building professionals who create these artefacts and the financing formulae that enables them all co-evolve as a building culture that tends to serve the interests of decision-makers. The argument is not that building cultures are irrationally or maliciously manipulated, but that ‘relevant social groups’ (Cowan, 1989) within the building culture make seemingly rational design decisions, based on coherent epistemological assumptions, without recognizing how their own frames influence technological decision-making (Guy & Shove, 2000; Pinch & Bijker, 1985; Shilton, 2013; Winner, 1999 [1980]; Woodhouse & Patton 2004). This proposition provides the context in which the case of net-zero housing in Austin, Texas, can be empirically considered.

**Empirical analysis**

The empirical analysis below was conducted to understand epistemological conflict and ask the following question: How did some actors in the selected case make design decisions, or struggle with the software to make different ones, without recognizing the competing interpretive frames embedded in their own professional judgment, and in the software itself? The data required to answer this question were collected using five research methods.

First, the (partial) literature review in the first section provides one way to interpret the case analysed in the second.

Second, one analyst was engaged in ‘participatory action research’ (Kemmis & McTaggart, 2003) as an employee of the community design centre for three years, from July 2009 to August 2012. In that period he was directly involved with the energy modelling of the evolving housing designs. He experienced, then, the day-to-day decision-making process of all the actors.

Third, the same analyst conducted a series of five semi-structured interviews (McCracken, 1988), conducted between June 2013 and April 2014 – after his employment ended – as part of his Master’s of Science in Sustainable Design thesis research at the University of Texas, which was supervised by the other two authors. The thesis supervisors reviewed interview protocols and advised on methods of interpretation. The interviewees were key decision-makers in the design and development team. They included:

- the owner of a local homebuilding company and a development partner for the project
- the executive director of the community housing development organization and a development partner
- one of the architects responsible for the first set homes to be built
- a code official from Austin Energy (AE) who served as the code and energy modelling advisor for the subdivision design
- the executive director from the community design centre who acted as the project manager for the subdivision and who was contracted to perform the energy modelling

In December 2013, the analyst ‘coded’ the interviews by hand and prepared ‘memos’ (Lincoln & Guba, 1985). This process identified dominant themes in the project narrative, including the controversies in technological decision-making that developed between the actors and the modelling software.

The fourth method employed to interpret both the historical and empirical analyses was to prepare ‘mappings’ which followed an actor-network methodology developed by Yaneva (2012). The maps graphically organized the actors interviewed in the study in relation to the historical analysis of the air-conditioning industry and energy modelling software development. These maps included not only people, but also the artefacts with which people engaged in the case. Graphically organizing the controversies helped to illustrate work-arounds and the influence of the software in decision-making.

Finally, the fifth method employed was a ‘member-check’, or asking one key actor in the case to review this text. Only minor corrections were suggested and made.
These qualitative, empirical research methods are not objective in the classical scientific sense. Rather, they seek to reconstruct multiple subjective understandings of the case through ‘triangulation’ (Denzin & Lincoln, 1994). According to Calabresse (2009, pp. 154–55):

Triangulation describes the use of multiple data sources and/or research methods in a study. This apparent overlap by the qualitative researcher seeks to address threats to validity and reactivity […] and researcher bias.

Rather than trying to provide a single, authoritative view of reality as does laboratory science, these qualitative methods provide multiple ‘situated perspectives’ (Haraway, 1995) of reality that embrace real-world conflict and uncertainty – which constitute the phenomena being studied. The sections that follow reconstruct and integrate the data from all sources as a single narrative.

Social construction of the Austin Climate Protection Plan (CPP)

The City of Austin in Texas, United States, has had a long history of being on the forefront of environmental policy (Moore, 2007; Portney, 2003; Swearingen, 2010) and helped lead the way in developing regulations to address climate change issues in the country. In 1990 the city’s publically owned utility, Austin Energy (AE), created the first green building programme in the nation, named the Austin Energy Green Building Program (AEGBP). According to the AEGBP:

Developing and maintaining our own Austin specific rating systems allows us the flexibility to carry out Austin’s aggressive climate protection goals. We use these ratings to pave the way for energy and building code changes that will reduce building energy use. This continuous improvement cycle benefits everyone in our community.

(AEGBP, 2014)

As stated, the city – through its highly progressive utility – uses the green building programme as a means to test and advance code changes to ‘reduce building energy use’ in order to achieve publically supported climate protection goals. Part of this strategy has been for the city regularly to adopt the latest version of the IECC and to amend its basic requirements to make the city’s energy code more stringent than the standard.

An even more substantive action was taken in 2007 when Austin City Council passed aggressive regulations to reduce further the carbon generated in the city. The plan, called the 2020 Climate Protection Plan (CPP), is conceived as a comprehensive attempt to reduce system-wide energy consumption and carbon production (City of Austin, 2010).

System-efficacy model of evaluation

Austin’s CPP envisions the municipal energy system as inclusive of five subsystems (City of Austin, 2014):

- municipal operations: make all city fleets, facilities and operations carbon neutral by 2020
- energy generation planning: reduce Austin’s total energy use to 800 megawatts (MW) and increase the renewables portfolio to 35% of the power mix by 2020
- energy efficiency: enforce energy-efficiency codes on current homes, commercial buildings and new construction
- community-wide emissions: develop an inventory of community greenhouse gas emissions, as well as targets and strategies for reduction
- carbon neutrality assistance: provide tools such as offsets for individuals to mitigate their own emissions

Of these five subsystem components, the third, energy efficiency, includes home energy code enforcement as one action initiative. Units of housing were, then, understood by the local design community as units integrated within a municipal energy ecosystem.

It is relevant to note here that the third criterion uses the modern, or normal, language of ‘energy efficiency’ as a strategy to achieve the non-modern, or post-normal, goal of system efficacy. This is not a contradiction but one example, as argued above, of how individuals frequently inhabit multiple overlapping frames, at least until those frames come into conflict through action (Moore & Wilson, 2013).

Defining the problem at hand

One sub-plan of the CPP is the Housing and Building Plan. Its stated goal is to ‘make Austin building codes for both residential and commercial properties the most energy efficient in the nation’. One sub-plan strategy to accomplish this goal is to revise the city’s building energy code to require, by 2015, all new homes constructed to be net-zero energy capable (City of Austin, 2007). To define such a standard better, the city council commissioned a taskforce to study ways the current energy code could be modified to achieve the defined goal. Named the Zero-Energy Capable Home (ZECH) Taskforce, the volunteer
citizen group included members from the building, design and construction disciplines, an environmentalist, a concerned citizen, building scientists and city staff. This local design community was charged further to define, or consciously frame, the problem in concrete terms that could envision both a sustainable future and be regulated.

Following roughly a year of work, the ZECH Taskforce defined ‘zero-energy capable homes’ as ‘homes that are energy efficient enough to be net zero energy [...] with the addition of on-site, or its equivalent, energy generation’ (City of Austin, 2007, pp. 1–2). By 2015 this level of energy efficiency would be approximately 65% more efficient than homes built to the City of Austin Energy Code in effect in November 2006. The taskforce then recommended an amendment to the existing code to implement their recommendation. The City Council complied by phasing-in stricter requirement in three-year increments, so that a 65% building energy-use reduction would be reached by 2015.

The managers at AE asked: But how might the city determine if a house is, in fact, net-zero, or net-zero capable? One practical answer is that the city need only compare, from meter readings, energy produced and consumed over a year. As a practical matter of policy and code compliance, that method of demonstrating compliance was not only politically controversial, but also practically unworkable. The problem arises due to the need to provide regulatory approval for, or economic benefits to, a net-zero home before, not after, it is built. Therefore, as a matter of policy and regulation, specifications and design performance standards needed to be created to judge whether a building is, or is not, considered net-zero capable at the time of design. In other words, the procedure was framed in terms of the normal decision-making tools constructed and operated by moderns – which could only measure unit efficiency – not the post-normal goal articulated by non-moderns. At that time, however, no one foresaw the inevitable conflict because everyone thought they were on the same team.

In 2007, all parties agreed that the policy was an aggressive move on the part of the City of Austin. However, the definition of zero-net energy adopted by the taskforce was based only on energy modelling and historical data. AE, as a thoroughly modern institution, prudently required that the progressive (and politically controversial) code amendments be tested empirically to determine (1) if both energy consumption and affordability goals could be met, and (2) what impact a net-zero neighbourhood would have on the municipal grid. As a result, AE sought a pilot project that could be used to demonstrate the feasibility and effectiveness of the code.

Epistemological conflict in practice

The housing subdivision ultimately selected was a joint venture between a local homebuilder (‘the builder’), with strong ties to the East Austin neighbourhood in which the project is built, and a local community housing development organization (‘the CHDO’, pronounced ‘choo-de-o’) whose mission is to provide affordable housing for residents within the same neighbourhood. In addition to the affordability and community development aspirations of the project, AE agreed to provide photovoltaic arrays at no cost to the project. However, in return for the arrays, the utility required that: (1) the project be designed to be net-zero, as defined by the taskforce, (2) the project team develop energy models of the unit designs that demonstrate annual energy use to be compliant with the proposed ZECH code standards, and (3) post-occupancy energy consumption data would be shared so that AE could empirically test its decision-making tool (energy modelling software).

A design team was assembled by the CHDO that included a community design centre (‘the design centre’) to assist with project management, as well as four architectural firms (‘the architects’) to design the homes. In order to fulfill the requirements for the pilot study, the architects were contractually required by the CHDO to produce designs, as shown by the energy modelling tool selected by AE, to be 54% more efficient, which was the code requirement at the time of construction in 2008–09. AE, representing the modern frame, also recommended that the project team use the DOE-2-based EnergyGauge as the compliance modelling software. Since the architects did not have the capacity to build the energy models themselves, the design centre was tasked with managing and building the energy models for the architects. In addition to a strict energy budget, the homes were also limited to a tight US$125/ft² construction budget to meet the affordability goal mandated by the CHDO.

The design process for the homes proved to be a unique experience for all the members of the design team (the CHDO, the homebuilder, the architects and the design centre). The primary goal for the CHDO was to create affordable housing for the residents of East Austin. The selected neighbourhood is an underserved community with mostly minority residents. However, being adjacent to downtown, East Austin for the past decade has faced strong gentrification pressures (City of Austin, 2001). Many long-time residents have either been forced to move out of the neighbourhood, because of escalating property taxes, or effectively compelled to sell because of the rapidly escalating cost of living and seemingly high profit they could realize. Both the homebuilder and the CHDO wanted to ensure, then, that this project would attract either residents who had previously been forced out of the
neighbourhood or current residents who required a means to stay. In the context of city-wide or non-modern system efficacy, it was important that the project serve the interests of local residents and thus avoid their geographic displacement, which would only introduce new problems and latent costs in other parts of the system (Lees, Slater, & Wyly, 2010). One obvious example is increased vehicle use to commute to work – a sustainability metric not accounted for in a modern energy model (but which might be addressed in other parts of the Climate Plan). A less obvious example is the ‘social capital’ (Bourdieu, 1984 [1979]) lost to displaced residents, which must be substituted for with financial capital from other parts of the system. These extra-scientific variables, championed by the CHDO, were respected by the modern analysts from AE, but were framed by them, and their decision-making tool, as being outside the system being modelled and designed. Where moderns were comfortable with the rigours of ‘normal science’ they were uncomfortable with the uncertainty of ‘post-normal science’ (Bidwell, 2009) and post-normal design being requested.

The design process was an iterative one, based on design guidelines issued by the CHDO. The architects first submitted schematic designs to the design centre. The design centre, in turn, modelled the designs based on guidance from AE. The IECC, as part of its legacy from HVAC analysis, prescribes very specific operating conditions that must be used for the energy model – as interpreted by AE. For example, temperature settings used for the model were determined to be 78°F for cooling and 68°F for heating. Other assumptions, such as building size and the number of occupants per square foot, are also prescribed as part of the code protocol. AE closely reviewed the models to ensure that they were generated with the protocol of the Austin energy code. Once approved, the design centre returned the results to the architects and recommended adjustments to their designs, based on the modelling, in order to meet the energy consumption goals.

After a few iterations of the evolving designs, the design team realized that the standard high-efficiency building specifications (typically prescribed by the Austin Energy Green Building guidelines), produced an energy model result that was at least 5% over the prescribed target. And even more startling was that, due to the requirements of a well-intend grantor, ResNet HERS standards (discussed above), as well as mechanical ventilation, would be required to meet the ASHRAE 62.2 fresh air standard. The most energy-efficient way to ventilate a building mechanically is to use an energy-recovery ventilator (ERV). This type of equipment is not normally used in housing construction (in Texas) and was an expensive addition to the project. The addition of the ERV made it clear to the design team that in order to achieve the last few percentage points to meet the energy efficiency goal, as prescribed by the energy model, more expensive and more modern technology was needed.

The ERV conflict was epistemological (Romancheck, 1971). From the perspective of moderns, it was necessary to build a very tight building to meet the net-zero energy goal. In turn, it became necessary to install ERVs so that they would know from a distance that healthy indoor air quality (IAQ) standards would also be met. But, from the post-normal perspective of the non-moderns interested in extra-scientific variables, knowing actual IAQ standards might be satisfied in ways not anticipated by the decision-making software. For example, a relatively inexpensive and more efficient ventilation system, plus additional insulation, might be an equally efficient thermodynamic solution. A more difficult epistemological and ethical question would be to go beyond shallow thermodynamic calculations and require humans, either residents or staff, to operate windows or passive ventilators. But, how would the builder ensure good IAQ for tenants, as required by a lender, and is it fair to require already vulnerable residents to operate unfamiliar equipment when the rich do not? The default setting in the decision-making tool placed more confidence in the habits of machines (for which data exist) than in those of humans (for which little data exist), even though many have argued for the ontological and health benefits of engaging humans in building operation and climate control (Frampton, 1995; Younger, Morrow-Almeida, Vindigni, Andrew, & Dannenberg, 2010).

For a second example, in order to meet the budget, designs were originally specified with conventional (although high-performing) direct-expansion air-conditioning systems. To capture the last few percentage points an even more efficient system was required – either variable speed inverter air-conditioning systems (known as ‘mini-splits’) or geothermal heat pumps. Both options were expensive and needed to be examined with great care if they were going to be used. In addition, the architects, who were contractually obligated to produce designs that met both the energy-efficiency requirement and the tight US$125/ft² budget, were nervous that the costs were escalating. In response to growing anxiety and conflict, the design centre organized a mediation session with the architects and AE to strategize ways in which the team could satisfy the problem framed by moderns in the most economically responsible way, yet avoid succumbing to uncritical point counting.

The meeting proved to be productive. A main topic of discussion at the meeting was the accuracy of the energy modelling results. Team members believed that the designs would actually perform better than the models were predicting. The CHDO director, in
The energy model does, however, report the amount of energy used by the clothes dryer separately from miscellaneous loads. The CHDO director observed that low-income tenants in other locations generally use clotheslines to dry their clothes. Modern code-makers, on the other hand, assumed that an electric dryer would always be used. This assumption was not, it must be stressed, based on any empirical data about the residents of this or any other project. Rather, it is the kind of judgment moderns tend to make without recognizing how their own way of framing laundry influences design decision-making. In this case, however, the amount of energy attributed to clothes drying by the model was found to be excessive, even by AE analysts, when presented with empirical evidence presented by the CHDO director. This is to say that their frame of interpreting laundry as a social practice was realigned. In the end, AE agreed to cut that load in half, if the design team designed a clothesline into the project. It is significant that the frame concealed in the modelling protocol was successfully challenged by the critical process managed by the design centre – a luxury rarely found in conventional practice, but one that demonstrates how collective action by those who inhabit competing frames can lead to new or ‘post-normal’ ways of interpreting reality.

As a follow-up to the mediation, the design centre prepared a sensitivity study, which systematically analysed the relative effectiveness of the various technical alternatives considered. These measures accounted for about 3% in additional savings, and reductions in dryer loads contributed another 2%, for a 5% overall energy reduction. Together, these design decisions brought the home designs to within 3% of the prescribed 54% energy reduction required for 2009. The design centre, then, acting as project managers, gave instruction to the architects to complete the designs based on the information from the sensitivity study and prepare a set of bid documents. They further instructed the architects to include bid alternates for the various measures from the study so that they could, based on cost–benefit analysis, choose the final design specification.

In the first-phase of construction in 2012–13, eight units were built at the stipulated cost of US$125/ft² using the technologies suggested by the energy modelling sensitivity study, including a geothermal heat pump HVAC system. In the final assessment, the energy model predicted an efficiency rating 2% better than the 34% target, or 56% lower than the 2006 IECC – a significant achievement.

Although this outcome sounds mathematically precise – within the shallow system limits established by the modern frame – in a post-occupancy evaluation the individual units themselves exhibited a very significant spread, both positive and negative, as compared with modelled energy predictions. Similar results were documented in a New Buildings Institute (NBI) study of LEED-certified buildings (NBI, 2008). Although such results were superficially acceptable to AE, in fact they demonstrate just how poorly the energy model anticipated contextual operation of individual construction units. In other words, the addition of very expensive technologies, such as ERV and geothermal heat exchange, may not have been the most reasonable choices viewed with non-modern epistemological assumptions. They were, however, incentivized by the framework of interpretation embedded in the modern decision-making tool.

Discussion
The preceding section argued that the purpose of the empirical case study analysis was to test the theory developed in the first, or historical, section of the paper. The empirical analysis demonstrated that the categories of modern and non-modern practitioners of sustainable development did fit the actors in this technological drama. What the case also demonstrates is that none of the practitioners interpreted conditions from only one frame. Rather, actors in the case may have been more comfortable inhabiting either the modern or the non-modern frame, but they were able to align their frame with others when collaborative
action appeared to be reasonable and in their interest, as was the case with regard to clothes dryer loads.

Assuming that readers so far accept that the theory has been supported by the case study, it remains reasonable to question the degree to which the finding of any singular case can be generalized, or applied to conditions elsewhere. Although there has been considerable debate about the statistical value of case studies (Lincoln & Guba, 1985; Manning & Cullum-Swan, 1994; Wang & Groat, 2013), researchers who embrace a world view consistent with complex adaptive systems, like du Plessis and Cole (2011), tend to side with sociologist Bent Flyvbjerg in arguing that:

One can often generalize on the basis of a single case, and the case study may be central to scientific development via generalization as supplement or alternative to other methods. But formal generalization is overvalued as a source of scientific development, whereas ‘the force of example’ is underestimated.

(Flyvbjerg, 2006, p. 228)

The point to be made here is not that the specific conditions of the modern/non-modern conflict found in Austin are somehow universal. The Austin case is, however, a forceful example of how individuals generally fail to recognize how misunderstandings in practice frequently derive from fundamental epistemological conflict. Perhaps a more important observation to be made is that this investigation demonstrates the strategic research method used – frame analysis – to be a very helpful tool in understanding the how social conflicts, in Austin and elsewhere, contribute to and are at least partially resolved through technological change (Bijker, 1987; Yaneva, 2012).

The usefulness of the particular findings itemized below ultimately depends on the ability of future analysts to reconstruct the local building cultures in which they wish to act. In other words, these seven findings become useful only when analysts can adapt them to other local contexts.

Conclusions
In sum, this historical and empirical analysis yields seven primary findings:

- The problem definitions constructed by non-moderns, in Austin and elsewhere, are too frequently subverted by implementation procedures governed through the interlocking modern interests of code-makers, energy-modellers and real estate lenders – even though both groups articulated a desire to develop ‘sustainably’. This is to say that modern standards and artefacts carry the suppressed assumptions and frames of their modern makers, not the frames of non-moderns who question the inadequacy of normal decision-making tools in the post-normal conditions of climate change. In the drama played out in Austin, the modern framework mostly embraced by AE limited the variables at play to the old science of shallow thermodynamics. These are variables that engineers could control in a context-independent system, at a scale no larger than the building envelope. In contrast, the non-modern community fabricated a problem definition, based on the new sciences of sustainability and climate change, which also includes a host of variables from a context-dependent environment, at a system scale equal to, or larger than, the city-region. Their problem was, then, defined not as shallow thermodynamics, but as a problem of system-wide fossil fuel consumption and carbon production that has potentially catastrophic consequences. As a result, the non-modern community in this case was required to use the decision-making tools and data developed by moderns to achieve goals articulated a century ago. By adopting the codes and standards developed by moderns, the city ironically prevented itself from fully resolving the problem defined through a thoughtful democratic process. In other words, normal codes of implementation tend to reconceptualize novel ideas in the making.

- The argument here is not that one building culture is less or more rational than the other, but that their epistemological assumptions are different. Haraway (1995), Benhabib (1996), and Latour (2004), among others, have argued in favor of value-rationality in democratic societies, which is the recognition that different social groups perceive reality differently and act rationally to maintain their own interests within it. This logic does not suggest that traditional building science in general, or DOE-2 in particular, is wrong. Rather, the argument is that modern building science is incomplete and applied poorly by code-makers and mortgage-lenders. Yet another way to say this is that the use to which energy is applied alters reality. Or better, energy is always used in a social context that has different consequences for different social groups. Assessing such eco-sociotechnical consequences is a necessary dimension of post-normal design decision-making.

- In any technological drama, what did not happen can be as important as what did. In the context of Austin’s affordable, net-zero energy housing project, moderns controlled decision-making based on the relative efficiency – as measured
by DOE-2/EnergyGuage – of units of construction; air-conditioning systems, wall assemblies, ERVs, heat pumps, clothes dryers, clotheslines, and hundreds of other technologies. The result of this kind of decision-making is that the first eight units to be constructed in phase one, on average, consume 56% less than the energy allowed by the 2006 International Energy Efficiency Code. These results can be said to be very successful in the terms defined by moderns in the mid-20th century. However, the consequences of the energy code for the efficacy of the municipal system as a whole, as defined by the 2020 Austin Climate Protection Plan (CPP), have largely gone unassessed. Other variables could have been tested in the pilot project, which would have had even greater impact on city-wide energy consumption. DOE-2 cannot, for example, easily measure the consequences of changing zoning densities (Moore & Wilson, 2013); property set-back distances (Shove & Moezzi, 2002); dwelling-unit size (EIA, 2014; Hirst, Marlay, Greene, & Barnes, 1983); smart energy controls (Rijal, Humphreys, & Nicol, 2009); neighbourhood-scale distributed heating, cooling and water catchment (Rezaie & Rosen, 2012); or tenant education (Leslie, Pearce, Harrap, & Daniel, 2012). Although moderns, as generally represented by AE in this drama, acted as a benevolent partner, they were limited to rationally manipulating the variables for which they had the tools and data to control. It is, in theory, possible consciously to adjust the hundreds of set-points, or numerical settings for thermodynamic and other variables, now included in DOE-2 by attaching complex data schedules. In practice, however, it is highly impractical to do so. Rather, the default set-points considered to be neutral and natural by moderns are generally accepted uncritically by the design community. They are, then, what Bowker and Star (1994, p. 206) refer to as ‘frozen policy’. The city was, then, unable to demonstrate system-wide energy efficacy because it did not also include actors in the drama who have the authority, knowledge and practical skills to manipulate the variables (human and thermodynamic variables outside the building envelope) that influence system performance. The unfortunate assumption was that energy matters belong only to the energy department.

- Moderns have, over the past century, made significant progress toward the contextualization of thermal calculations. For one example, the inclusion of dynamic weather data is now common. In another example, also drawn from the case, is that the HERS standard allows the set-point temperature for cooling to be increased by 0.5°F if a ceiling fan is installed. The rationale behind this small adjustment is that human behaviour will be modified by the experience of convective cooling in addition to temperature reduction. This small nod to human behaviour, habits and inhabitation opens a much larger, and necessary, conversation concerning the human side of any eco-sociotechnical system. Although moderns have been historically dismissive of the kind of knowledge produced by the social sciences (Flyvbjerg, 2006), it appears that such hybrid methodologies are required to make sense of the data gleaned from this and other cases. The general approach of ‘regenerative design’ (Cole, Oliver, & Robinson, 2013; Robinson & Cole, 2015; Svec et al., 2012) is the most promising alternative.

- The technological momentum of the unit-efficiency method of design and assessment has created a crisis of internal validity in the project of realizing sustainable development. The concept of internal validity exists to question if calculations actually measure what is said to be measured, and thereby support sound decision-making. The argument made here is that measuring the relative efficiency of units of construction, using digital energy models based primarily on the assumptions of shallow thermodynamics, is not the same as measuring system-wide efficacy as defined above. Selecting a suburban rather than an urban site to build, for example, might even harm the efficacy of the ecosystem studied, yet it is not considered in most energy models or technological codes. As argued above, by atomizing the problem at hand, problem-solvers tend to obscure causal relationship in the larger system (outside the building envelope) and place smaller problems in the hands of self-interested social groups. The internal validity of energy modelling requires, then, post-normal tools and corresponding data that can also measure the dynamic human side of the system.

- If measuring unit efficiency (as do the digital models developed to date) fails to provide the data required to make reasonable choices, an alternative suggestion briefly considered above – made by an AE analyst directly involved in the case – would be to measure and regulate household consumption. Although this option is attractive from an accounting perspective, it introduces ethical questions concerning privacy and equity that current models avoid. In other words, making household consumption a matter of regulation would require a completely new method of calculation and a new politics.

- Finally, this analysis demonstrates how the competing epistemological assumptions held by the
moderns and non-moderns retard progress toward achieving the goal of sustainable development. The analysis suggests that achieving this elusive goal will require not only new tools to measure suppressed variables and new data concerning human variables, but also new kinds of professionals trained to see, measure and test nested ecological systems. This requirement, in turn, demands the self-conscious construction of new, genuinely interdisciplinary, educational formats at all levels. Overcoming, or subsuming, the epistemological divide that separates moderns from non-moderns is required before the human community can co-construct efficacious urban ecosystems.

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References
politics of knowledge (pp. 175–194). Bloomington, IN: Indiana University Press.


### Endnotes

1 As suggested in the introductory paragraphs, and to avoid any confusion, it is helpful to amplify the difference between ‘frames’ and human beings. Frames are logically coherent and consistent ways of both interpreting and anticipating reality – they are not the truth. Human beings, however, are rarely so coherent or consistent. Rather, people switch frames as conditions around them change. It is, then, reasonable and possible for a ‘modern’ energy analyst to inhabit a ‘non-modern’ frame when conditions warrant, or vice versa. It is this context-dependent flexibility of interpretation that makes ‘frame alignment’ (Snow et al., 1986) possible. In other words, frames are more like an acquired habit than a cognitive prison.

2 This claim is supported by data developed by the US Energy and Information Administration (EIA) (2014). In this study of housing stock of the United States in 2009, energy per square foot (efficiency) decreased, but total residential energy consumption rose after the 1970s (from a base of about 50 mBtu prior to 1970). In other words, units of housing were more efficient, yet consumed more energy overall. Other variables, primarily house size, account for the change.

3 See also Ruth Cowan’s analysis of the historical development of the electric refrigerator (Cowan, 1985).

4 In his recent book, Kiel Moe makes this observation far more forcefully (Moe, 2014a). Following Lloyd and Pagels (1988), he adopts the term ‘thermodynamic depth’ (p. 17; cited in Moe, 2014c) to account for the energy exchanges that take place between the building and the external environment. To emphasize the point, he argues, ‘no system boundary needs to be blasted wide open more than the assumption that the building envelope is the system boundary of a building’ (p. 46). In Moe’s view, then, even the most sophisticated contemporary thermodynamic calculations are shallow.

5 Over-sizing HVAC systems can, however, lead to humidity problems – a consequence not considered herein.

6 For a review of ‘regenerative design’ as a social movement, see Walsh and Moore (2015) and Moore and Walsh (2012).