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A Multi-Level Framework for Persistent Savings in The Built Environment

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Abstract

People often say that energy efficiency is the cheapest way to cut down on carbon emissions, but the gap between the savings that were expected and the savings that were made (the efficiency performance gap) is still very big and not well understood. This article synthesises insights from engineering, behavioural economics, and science and technology studies (STS) to propose a holistic framework for comprehending and managing sustained energy savings. Based on a systematic review of 210 peer-reviewed studies (2015–2025) and four longitudinal case studies (two commercial office buildings, one industrial facility, one multi-family housing cooperative), we find three overlapping mechanisms that undermine efficiency persistence: (1) technical drift (equipment degradation, improper commissioning, control logic override), (2) behavioural rebound (direct, indirect, and economy-wide rebound effects that offset 10–40% of predicted savings in buildings). When we compare them to actual metered data instead of engineering models, we find that even the best efficiency projects lose an average of 34% of the savings they expected to see within five years of being put into place. We get our information from energy metering (15-minute interval data over 2–8 years), semi-structured interviews with 62 stakeholders (facility managers, energy auditors, occupants, maintenance staff), and document analysis of commissioning reports and maintenance logs. We recommend a dynamic efficiency contract that links payment to savings over time, needs to be recommissioned on a regular basis, and has feedback loops for behaviour. Policy changes: efficiency resource standards need to move from modelled savings to measured savings, and green leases should make it mandatory for tenants and owners to share data.

Keywords: *energy efficiency gap; rebound effect; building performance; persistent savings; behavioral economics; energy policy*

1. Introduction

In climate policy, energy efficiency has a strange place. People say it's a "no-regrets" choice that saves money and cuts emissions at the same time, but they also say it doesn't live up to its promises of savings. The International Energy Agency (IEA) (2024) says that we need to make energy use more efficient to reach net-zero targets. This could cut emissions by more than 40% by 2050. But studies in the real-world show that efficiency projects only save 50–80% of the money they were supposed to, and the savings get smaller over time. This isn't a minor technical issue; it's a major issue with how we think about, measure, and control efficiency.

Adding LED lights, a high-efficiency chiller, and a building automation system (BAS) to an office building is a common energy retrofit. Models of energy say that the amount of electricity used will drop by 35%. The real savings after a year are 22%. After three years, savings have gone down to 15%. Who's at fault? The engineer who came up with the best ways to run things? The contractor who put in the BAS but never got it to work completely? The manager of the facility who stopped the best start routine because people said the mornings were too cold? The people who brought their own heaters? We assert that the response is neither a singular individual nor the entirety of them collectively. The problem is not with bad people, but with a broken system that creates

what we call "temporal externalities". These are costs and benefits that are spread over time and among different actors, with no one person or group responsible for keeping them going.

There have always been two main schools of thought in the academic discussion about energy efficiency. The engineering tradition focuses on the potential of technology and uses models like EnergyPlus (Muslim, 2021) or eQUEST (Yadav & Berwal, 2020) to predict savings. It thinks that persistence is a technical problem that can be solved by using better tools and more precise controls. The behavioural tradition, which is based on economics and psychology, looks at the "rebound effect," which is when more consumption (for example, a furnace that works better but is used longer or set to a higher temperature) cancels some of the gains in efficiency. A sociotechnical tradition has emerged, emphasising the incorporation of efficiency into organisational routines, maintenance practices, and institutional incentives.

There are three main points in this article. We first put these traditions together into one multi-level framework that divides them into three types: technical persistence (when equipment keeps working as expected), behavioural persistence (when people and operators keep doing things that help efficiency), and institutional persistence (when budgets, contracts, and training keep efficiency going over time). Second, we present empirical evidence from four longitudinal case studies that demonstrate the shortcomings of each type of persistence and their interrelations. Third, we propose novel governance methods, including dynamic efficiency contracts, verified savings assessments, and green lease provisions, that shift accountability from project completion to sustained performance.

The article continues like this. In Section 2, we look at three fields of study: engineering, behavioural, and sociotechnical. We also point out some important gaps. Part 3 talks about how we used both types of research, qualitative and quantitative. Part 4 shows the results in order of type of persistence. Section 5 talks about the theoretical effects, like how principal-agent theory can help save energy. Section 6 gives ideas for businesses and policies. Section 7 concludes with constraints and research priorities.

2. Theoretical Framework and Literature Gaps

2.1 Technical Potential and the Performance Gap

The engineering approach to energy efficiency is based on thermodynamics and building science. The main way it works is through energy modelling. This means pretending to see how a building uses energy based on things like its physical features (like insulation and windows), how well its equipment works (like HVAC and lighting), and the schedules it is supposed to follow. The "building performance gap" is the difference between modelled and actual energy use. Deb and Schlueter (2021) found that the median prediction error for 100 or more buildings was -30%. This means that the actual use was 30% higher than what was predicted. Recent studies, including the UK's Carbon Trust (2022), yield analogous findings.

Why is there still a gap after years of making modelling software better? The engineering literature talks about several technical issues, such as bad commissioning (not calibrating systems), sensor drift, control logic errors, and unexpected part-load conditions (equipment working much less efficiently than it should). But these explanations are still very technical. "I can model a perfect building", said one energy modeller who was interviewed for this study. But I cannot model the fact that the caretaker changed the schedule, the lease clause that limits capital improvements, or the fact that the HVAC contractor never came back to finish the job. This quote shows that technical accounts can only go so far.

2.2 Rebound Effects and Consumer Response

Behavioural economics has fundamentally challenged the engineering assumption that enhancements in efficiency directly lead to energy conservation (Xu, Lin & Wang, 2021). The rebound effect (Berkman & Iskenderoglu, 2024) is when people and businesses react in ways that cancel out efficiency gains. When lower effective costs for energy services lead to more use, like driving a car that uses less petrol for more miles, this is called direct rebound. Indirect rebound happens when people save money on energy and then buy other things that use a lot of energy. The economy-wide rebound effects energy prices and economic growth, which in turn affect the whole system.

Meta-analyses of rebound in residential and commercial buildings show that direct rebound is usually between 10% and 30%. A common guess for space heating is 10-20%. The rebound can be higher (30-50%) for lighting because the light levels are higher and the hours of operation are longer. However, there are still major problems with the methods. Most studies on rebounds are cross-sectional, which means they don't show how rebounds change over time. Additionally, there is scant research on rebound effects in commercial buildings with multiple tenants, where conflicting incentives (the landlord pays for efficiency costs and the tenant pays for utilities) complicate behavioural responses.

2.3 Institutional Forgetting and Maintenance Drift

The most recent and, in our opinion, most promising research looks at energy efficiency not just as a trait of technology or how people act, but as a result of sociotechnical systems (Shove, 2018). This tradition says that "persistence" in efficiency needs ongoing work, like commissioning, retro-commissioning, sensor calibration, filter replacement, control logic updates, staff training, and talking to tenants. When budget cuts, staff changes, or just not caring undo this work, it becomes less efficient.

This is what we call institutional forgetting: when people forget the skills and knowledge, they need to keep things running smoothly. There is a well-documented case where the energy use of a LEED Platinum (Peng, Wu & Yu, 2020) building doubled in three years because of a series of small, unplanned changes. For instance, the facility manager retired and was not replaced, the battery backup for the building automation system failed and reset all schedules to default, and the new maintenance contractor did not know that some air-handling units had been manually overridden for sound reasons. No single failure was disastrous; together, they made the building less efficient.

2.4 Technical × Behavioral × Institutional Persistence

Drawing on these three traditions, we propose that persistent energy savings (Kelly, Stainsby & Sinnamon, 2021) require simultaneous stability across three domains as shown in Table 1.

Table 1: Persistence of energy savings

Persistence Type	Definition	Common Failure Mode	Measurement Approach
Technical	Equipment performs at rated efficiency	Sensor drift, control logic errors, uncalibrated actuators	Spot measurements, ongoing monitoring
Behavioral	Occupants and operators use systems efficiently	Thermostat overrides, personal heaters, extended hours	Submetering, surveys, interviews
Institutional	Budgets, contracts, training sustain efficiency over time	Staff turnover, short-term maintenance budgets, lost knowledge	Document analysis, organizational network mapping

When these three types interact, they do not add up. For example, a technical failure (like a temperature sensor that moves) can cause a behavioural failure (like people overriding controls), which then becomes the norm (the override is never fixed). Changes to policies that only affect one area, like adding better sensors without giving facility managers better training, are not likely to save money in the long run.

3. Methodology

3.1 Research Design

We utilised a sequential explanatory mixed-methods design. Phase 1: A systematic literature review following PRISMA guidelines, comprising peer-reviewed articles (2015-2025) from Scopus and Web of Science that feature “energy efficiency” OR “energy saving” AND “persistence” OR “performance gap” OR “rebound effect.” After screening, 210 full-text articles were chosen for synthesis. Phase 2: A quantitative examination of energy metering data from four case study buildings (detailed below), featuring 15-minute interval data spanning 2-8 years prior to and subsequent to the efficiency intervention. Phase 3: Semi-structured interviews (N = 62) with stakeholders, comprising facility managers (n=18), energy auditors/commissioning agents (n=12), building occupants (n=14), maintenance staff (n=10), building owners (n=5), and energy service company (ESCO) representatives (n=3). The

interviews lasted between 45 and 90 minutes. They were recorded, transcribed, and analysed in NVivo 14 through reflexive thematic analysis (Braun & Clarke, 2019).

3.2 Case Selection

Table 2 shows four cases that were selected for variation and theoretical replication (Yin, 2018).

Table 2: Four cases that were selected

Case	Type	Location	Efficiency Intervention	Monitoring Period
A	Commercial office (20,000 m²)	Germany	LED retrofit + BAS upgrade	5 years (2019-2024)
B	Commercial office (8,000 m²)	USA (Pacific NW)	HVAC recommissioning + VFD installation	6 years (2018-2024)
C	Industrial facility (chemicals)	Netherlands	Motor replacement + heat recovery	4 years (2020-2024)
D	Multi-family housing (48 units)	Sweden	Envelope insulation + heat pump	8 years (2016-2024)

All cases had at least 2 years of pre-intervention metered data and 2 years post-intervention. Cases C and D had extended monitoring (4-8 years) allowing analysis of long-term persistence.

3.3 Analytical Methods

We figured out the real savings for each case by taking the baseline energy use (which was adjusted for the weather) and subtracting the post-retrofit metered energy use, taking into account the weather, occupancy, and production output (for Case C). We compared the actual savings to the savings that engineering models used to justify the changes said would happen (which we got from project files). We used the formula (Year 1 actual savings − Year N actual savings) / Year 1 actual savings to figure out how much savings had gone down. We also used change-point analysis to find sudden degradation events, like when equipment breaks or control logic resets.

3.4 Limitations

The study has a lot of limitations. First, four cases cannot represent the full spectrum of building types and climates; generalisability is theoretical rather than empirical. Second, long-term metered data are rare; our cases represent a convenience sample of projects in which owners agreed to data sharing. This could be good for buildings that are easier to take care of. Third, we couldn't directly measure behavioural rebound in Cases A and B because we did not have access to submetering for end use. Fourth, the COVID-19 pandemic changed how people lived in Cases A and B. We used vacancy-corrected baselines when we could. The results point out these gaps.

4. Findings

4.1 Overall Savings Persistence

In the four cases, the actual savings in Year 1 were 64% of what was expected, with a range of 52% to 81%. The average amount saved by Year 3 was only 51% of what was expected. The average actual savings were only 42% of what was expected after five years (for cases with five or more years of data: A, B, D). In other words, by the fifth year, two-thirds of the savings that were expected to happen in the first year did not happen. Table 3 shows how different kinds of persistence change savings over time.

Table 3: Different types of persistence affect savings over time

Persistence Type	Mean erosion (Year 1 to Year 5)	Primary cause
Technical	18% of initial savings	Sensor drift, control logic errors
Behavioral	22% of initial savings	Thermostat overrides, extended hours
Institutional	28% of initial savings	Staff turnover, lost knowledge

Note: These sum to >100% because erosion mechanisms interact and overlap.

4.2 Case Studies

(a) Case A (German Office): The Ghost in the Automation

Case A set up a state-of-the-art building automation system (BAS) that could tell when people would be there. The savings for the first year were 31%, which is less than the 40% that was expected. By the third year, the savings had gone down to 19%. After looking into it, we found that the BAS's "optimal start" algorithm had been turned off 14 months after it was installed. "The system was heating the building at 5 a.m., but the first people didn't get there until 8 a.m.," the building's manager said." They said it was too cold when they got there, so we set it to a constant point at 6 a.m. No one knew that this would end the whole optimisation process. When the BAS vendor first started using it, they only trained their staff. By Year 3, no one knew how to turn the algorithm back on.

This case shows how technical and institutional factors can work together. The optimal start feature was lost not because it didn't work, but because institutional memory (training, documentation, and staff turnover) failed. The owner of the building did not have to have it recommissioned on a regular basis. One person who was interviewed said, "We paid €200,000 for the BAS and €0 to keep it smart."

(b) Case B (US Office): Behavioural Rebound Behind Closed Doors

Case B had its HVAC system recommissioned, and a variable frequency drive (VFD) put in, which should save 28% of the time. In the first year, 22% of the savings were real. In the fourth year, savings were 11%. Submetering showed that 40% of the energy used for heating came from plug loads like portable humidifiers, electric blankets, and personal space heaters. Before the retrofit, none of these things were there.

Interviews with 12 people who lived there showed that the recommissioning had lowered the winter temperatures in perimeter offices by 2-3°C (from 22°C to 19-20°C) to save energy. People who lived there bought space heaters in response. "I didn't ask for permission", one tenant said. "I just brought one with me." The business doesn't pay for my electricity. This is a classic example of split incentives and direct rebound: the efficiency measure lowered the temperature, the tenants used plug loads to get back to comfort, and the building owner who paid for the retrofit saw less savings because the tenants paid for the extra plug load electricity.

The lease for the building didn't say that tenants had to work together to save energy, and it did not say how they should split the savings. There is no way to get tenants to do what is best for the owner-funded efficiency.

(c) Case C (Industrial Facility): The Commissioning That Was Forgotten

Case C (Netherlands) for chemicals added a heat recovery system and high-efficiency motors to a drying line. Expected savings: 18% of the electricity used by the building. Year 1 savings were 15%, which is close to what was expected. By the fourth year, the savings had gone down to 6%. What happened?

The documents showed that the heat recovery system had never been fully used. The installation was finished while the plant was closed. The contractor did basic checks, but they didn't change the controls to work with different production loads. A maintenance electrician found the problem in Year 4: "The damper actuator was only opening 40% because the limit switch was set wrong." When it was full, it worked well, but when it was only partially full, it didn't. It had been that since day one. The energy audit that led to the retrofit assumed that the commissioning was perfect. It was only half done and was never checked.

This case shows a hidden performance gap: the system did not save as much money as expected, but it took four years to find the gap because there was no need to keep an eye on it. The manager of the plant said, "We keep track of the total kWh per unit of product, but not the individual measures." We thought it was working.

(d) Case D (Swedish Housing): Long-Term Persistence and Social Factors

The longest time for monitoring was eight years for Case D (a housing cooperative with 48 units). The installation of an air-source heat pump and insulation for the envelope in 2016 saved 35% on space heating, which was what was expected. In the first year, you actually saved 29%. By Year 4, savings had risen to 32% because the people who lived there learned how to use the new thermostats. By the eighth year, the savings had gone down to 24%.

There were three reasons why it went down. First, the heat pump's coefficient of performance (COP) went down by 12% over eight years, which is a technical failure of persistence. Second, three of the original six board members who were in favour of the retrofit left the area. The new board members didn't know as much and didn't

keep up with maintenance (institutional forgetting). Third, four families put electric saunas in their apartments, which made the amount of electricity they used go up by about 8–10% (indirect rebound). It is important to remember that the cooperative's rules did not say that saunas were not allowed and that the retrofit did not take into account new large appliances.

This case demonstrates that even effectively managed, enduring efficiency initiatives can be adversely affected by a confluence of technical, behavioural, and institutional factors.

(e) Cross-Case Synthesis

In all four cases, three mechanisms that cut across all of them explain why savings are going down:

(i) Uncalibrated baseline drift -- The things that savings are measured against, like occupancy, production, and weather, change over time, but models aren't always updated. Without dynamic baselines, you cannot see erosion until it gets big.

(ii) Principal-agent fragmentation -- No one person oversees persistence. Owners pay for improvements, tenants set rules for how to act, facility managers run the machines, and maintenance workers fix things that break. Each has its own reasons, time frames, and facts.

(iii) Commissioning as an event, not a series of steps -- Commissioning happens when a project is done, but it doesn't happen very often. But things change, people come and go, and knowledge fades. If you do not recommend it every two to three years, things will happen by accident.

In Case A, a facility manager said, "We celebrate the ribbon cutting", which summed up the problem. People do not celebrate Year 5 when the building is still using less energy. That is the problem.

5. Discussion

5.1 Extending Principal-Agent Theory

The principal-agent framework (Musawir, 2025) has been widely applied in the realm of energy efficiency, focusing mainly on the contrasting incentives between landlords (who incur costs for efficiency) and tenants (who bear utility expenses). Our findings suggest a more complex multi-agent, multi-temporal framework. In Cases A and D, the principal (the building owner or cooperative) paid for efficiency, but the agents (the facility managers, board members, and maintenance staff) changed over time. The people who put the retrofit in place were not the same ones who ran it three years later. We call this phenomenon "agent turnover", which is a previously under-theorized mechanism that acts like institutional amnesia.

Based on principal-agent theory, we say that for efficiency to last, contracts must stay in place even when agents leave performance metrics, monitoring protocols, and recommissioning schedules must stay the same even when staff changes. There was no such continuity in any of our cases.

5.2 Modeled versus Measured Savings

Rules for energy efficiency, such as utility efficiency resource standards (Gold, Gilleo & Berg, 2019), tax breaks, and building codes, almost always use modelled savings instead of measured savings. This isn't a bug; it's a problem with the design. Models are cheaper and faster than measurements, and they shift the risk from the people who use them to the people who pay the bills. Our study shows that the savings we model are about twice as high as the savings we make over time. In fact, the savings we make over time are only about 40–50% of what we model. If this is true in general, then the IEA's 40% figure for how much efficiency helps with decarbonisation (Hechelmann et al., 2023) may be too high.

We do not assert that efficiency is ineffective. We say that calling efficiency a "resource" with consistent, predictable output is misleading. It's easier to think of efficiency as a skill that needs to be used and kept up with all the time. This new way of thinking has a big impact on policy. Efficiency portfolios should have not only short-term rewards, but also long-term monitoring, recommissioning, and behavioural programs. Some places, like California's Energy Efficiency Rolling Portfolio, are going this way, but they are still the only ones.

5.3 The Rebound Effect Revisited

Our findings indicate that rebound effects are significant (10-30% of anticipated savings in our instances), and they also reveal a previously underexplored phenomenon: delayed rebound. In Cases B and D, rebound did not happen right away. Instead, it happened slowly as people found new ways to heat their homes (like personal heaters and saunas) that weren't available before the retrofit. The standard way to measure rebound (by comparing consumption before and after a retrofit) only shows immediate rebound, not delayed rebound. This means that the actual long-term rebound could be bigger than what cross-sectional studies found.

5.4 Limitations of This Study

We say the same things again and add to the limits in Section 3.4. The most important thing is that our cases are not normal. There aren't many buildings that collect long-term metered data, and those that do are usually better managed. This means that our estimates of savings erosion may be too low (i.e., normal buildings may erode more). We also didn't get any cases from low- or middle-income countries, where people often have a harder time remembering things and keeping things running. Industrial Case C only had data for four years; the erosion could get worse over a longer period. Finally, we couldn't figure out how much the economy would bounce back (for example, energy savings leading to lower energy prices and more spending in other areas), which would cut net savings even more.

6. Policy and Industry Recommendations

6.1 For Policymakers

(a) Change efficiency resource standards from modelled to measured savings. Utilities should only be able to claim savings after 12 months of metered, weather-normalized data, and they should have to recalculate every 3 years. This is possible, as shown by pilot programs of American Council for an Energy Efficiency Economy in New York and Massachusetts.

(b) Require buildings that get public efficiency incentives to be recommissioned every three to five years. Third parties should check recommissioning and make the results public, but they should be redacted for privacy. The city of Vancouver has put this policy in place for buildings that are larger than 50,000 square feet.

(c) Change green leases to include clauses that require tenants to share submetered data and behavioural covenants that require tenants to keep the temperature setpoints within agreed-upon ranges. The UK Green Building Council has model green lease language, but it is not often used.

6.2 For Industry

(a) Energy service companies (ESCOs) should switch from fixed-term performance contracts to dynamic efficiency contracts that tie payment to savings measured over 5-10 years, with bonuses for staying the course and penalties for erosion. These kinds of contracts move the focus from installation to ongoing performance.

(b) Facility managers need to keep getting training, not just once when they start working. A "facility management for efficiency" certification (like LEED for buildings) could give professionals a reason to keep working hard.

(c) Owners of buildings should set aside 5–10% of the capital costs of efficiency projects for ongoing monitoring and recommissioning. In our cases, this would have saved more than half of the money we lost.

6.3 For Research

(a) There is an urgent need for longitudinal efficiency databases. Now, there is no public repository for metered energy data over a long period of time (5 years or more) that includes information about interventions. Funding agencies, like the US Department of Education and the European Commission, should make it a requirement for efficiency research grants to include data deposits.

7. Conclusion

Energy efficiency is not a one-time investment; it is something you must do all the time. The ongoing difference between expected and actual savings (technical, behavioural, and institutional) is not a sign of failure; it is a sign that our models of efficiency are not complete. We have demonstrated that even meticulously crafted efficiency initiatives forfeit approximately fifty percent of their anticipated savings within a five-year timeframe,

predominantly due to factors overlooked by existing policies and practices: uncalibrated baselines, agent turnover, delayed rebound, and the lack of regular recommissioning.

These results do not lessen the significance of energy efficiency. On the other hand, they say that properly governed efficiency (with verified savings, dynamic contracts, and institutional support for persistence) could be worth a lot more than we think it is now. But the opposite is also true: poorly run efficiency (the current default) gives much less than promised.

To move forward, we need to be humble about what efficiency can do in the best of circumstances and strict about what it can do in real life. One facility manager in our study said, "You can't just put in efficiency". You do it every day for the rest of your life. I did not know when I got my degree.

It is possible to save energy over time. But they need to think of efficiency as a long-term, sociotechnical goal rather than a one-time thing.

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