A Study of Human-Computer Interaction and Feedback Layers for Office Energy Conservation Behavior

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Abstract: Under the background of the dual carbon strategy, green office practices have become pivotal to sustainable development. However, relying solely on technological upgrades proves insufficient for effectively reducing energy consumption; stimulating and guiding employees' energy-saving behaviours is particularly crucial. Grounded in human-computer interaction perspectives and integrating cognitive ergonomics with dual-system theory, this study investigates how three types of energy consumption feedback (numerical, social comparison, and metaphorical) influence energy-saving intentions through emotional arousal (System 1) and cognitive load (System 2). A single-factor, three-level online scenario experiment (N=299) using the Hayes PROCESS macro tested dual mediation effects. Results indicate no significant mean difference in energy-saving intentions across feedback types. However, mediation analysis strongly supports the dual-system mechanism: emotional arousal significantly positively influences energy-saving intentions ($b = 0.3431$, $p < .001$), while cognitive load exhibits a significant negative inhibitory effect ($b = -0.1156$, $p = 0.0177$). Regarding specific mechanism activation, analysis revealed that only social comparison feedback significantly elevated participants' emotional arousal levels ($b = 0.2923$, $p = 0.0224$). This arousal indirectly promoted energy-saving intentions via an "intuition-emotion pathway" (Indirect Effect = 0.1003, 95% CI [0.0147, 0.1921]). This indicates that emotional motivation proves more effective in energy-saving behavior interventions, whereas merely increasing information volume does not further promote rational thinking. This study enriches the human-centered mechanism theory of energy feedback design, validates the applicability of the dual-system decision-making model in office energy-saving scenarios, and provides practical insights for green office system interface design. It suggests fully leveraging emotional motivation to activate users' intuitive engagement while controlling information complexity to avoid cognitive overload, thereby more effectively guiding energy-saving behaviors.

Keywords: Human-Computer Interaction (HCI); Ecological Feedback; Emotional Arousal; Cognitive Load; Energy-Saving Behavioural Intentions

1. Introduction

Within the global movement toward sustainable development, building energy consumption constitutes a significant proportion of overall energy usage. Office buildings exhibit particularly high electricity consumption during their operational phase, making the control of their power usage crucial for achieving energy conservation and emission reduction (Li et al., 2024)[1]. However, in practical scenarios, the potential for energy savings in office environments remains largely untapped due to insufficient employee initiative stemming from unclear organisational incentives and boundaries of responsibility.

In recent years, advancements in human-computer interaction technologies have established interactive ecological feedback-such as energy consumption visualisation-as an effective approach to enhance user awareness and drive behavioural change. Existing research has validated the energy-saving benefits of such interventions in real-world office settings. Despite this body of work, a critical gap persists: most studies fail to elucidate the underlying psychological mediating mechanisms through which interactive feedback influences users' behavioural intentions.

To address this gap, this study introduces the dual-process theory from cognitive ergonomics and psychology as the theoretical foundation for explaining feedback-driven behavioural interventions. This theory emphasises that users' behavioural decision-making involves two interacting systems: the rapid, intuitive, and emotion-driven “System 1”, and the slow, rational, and deliberative “System 2”. In energy-saving contexts, most energy consumption behaviours stem from System 1's inertial control (e.g., ‘unconsciously leaving devices switched on’). To disrupt this inertia and prompt users towards rational energy conservation, feedback design must incorporate ‘dual-trigger’ functionality. On one hand, it employs emotional arousal mechanisms to disrupt System 1's behavioural inertia, stimulating initial attention and motivation (Berney et al., 2024)[2]; while simultaneously reducing information processing difficulty to prevent users from disengaging from System 2's rational evaluation process due to excessive cognitive load (Hart & Staveland, 1988)[3]. Consequently, both the emotional contagion of feedback and the complexity of its informational structure will jointly influence the formation and intensity of energy-saving intentions.

Based on the aforementioned theoretical analysis and design inferences, this paper proposes the following research hypotheses:

H1: Different feedback types produce significant differences in energy-saving intentions.

H2: Consistent with dual-system decision theory, feedback type influences energy-saving intentions via two pathways: a positive “intuitive–emotional” pathway (emotional arousal) and a negative “rational–cognitive-load” pathway (cognitive load).

In summary, this study integrates diverse energy consumption feedback interfaces into a unified experimental framework. By measuring the mediating variables of emotional arousal and cognitive load, it delves into the underlying mechanisms through which feedback design impacts energy-saving intentions. This not only theoretically extends the application of dual-system decision-making models to environmental behaviour but also provides concrete guidance for interface design in green office systems. Subsequent sections will review relevant literature, present research methodology, data analysis procedures, and experimental findings, followed by theoretical and practical discussions, concluding with final observations.

2. Literature Review

2.1 Human-computer Interaction and Energy-saving Feedback Design

The core of the Human-Computer Interaction (HCI) field is to shape and guide user behaviour through interaction design (R et al., 2023)[4]. Within this framework, energy-saving feedback systems grounded in interaction design emerge as an effective practice for optimising energy usage. By fostering deep user engagement and interaction, such systems can effectively stimulate users' energy-saving awareness and proactive behaviour, thereby refining their energy consumption decisions(Soares et al., 2021)[5]. Among these, eco-feedback mechanisms-a key topic in sustainable interaction-emphasise presenting individual and collective energy consumption data in perceptible ways to facilitate cognitive renewal and behavioural change. Empirical research provides convincing support for these arguments. For instance, (Baedeker et al., 2020)[6] conducted a long-term Living Lab study in a real German office, employing interactive interfaces to optimise ventilation and air conditioning. Their findings demonstrated that user-engaged interactive feedback systems reduced energy consumption by approximately 20% without compromising comfort or productivity, validating the energy-saving potential of human-centred interaction design. Furthermore, scholars have introduced a novel mobile gamification platform demonstrating that ecological feedback systems significantly heighten user energy awareness by visualising historical and real-time consumption data, thereby catalysing behavioural change within office environments (Iria et al., 2020)[7]. Consequently, positioning feedback design as the core driver of behavioural intervention and systematically comparing diverse feedback paradigms emerges as a theoretical entry point for elucidating the mechanisms through which interface design influences user behaviour.

2.2 Feedback Design and Ergonomics

In the field of office energy conservation, a key objective of HCI is to design efficient human-machine interfaces (HMI) that facilitate users' transition from high-energy consumption habits to low-energy behaviours (Irizar-Arrieta et al., 2018)[8]. Regarding ecological feedback design, existing research indicates that the content presentation, visual approach, and timing of feedback significantly influence users' cognitive processing and behavioural responses (Sanguinetti et al., 2018)[9]. For instance, real-time numerical feedback enhances users' self-monitoring awareness, while historical trend charts facilitate behavioural reflection. Taking the Intelligent Building Environmental Monitoring (IBEM) system developed by Qinghua University as an example, this system employs data-driven feedback mechanisms to encourage users to transition from passive acceptance to active participation, offering an innovative approach to human-machine collaborative energy conservation in low-carbon office environments (Geng et al., 2022)[10]. Social comparison feedback, meanwhile, can stimulate normative compliance or competitive impulses (tagadmin, 2019)[11]. When users observe disparities in energy consumption between themselves and others, it motivates them to emulate energy-saving role models or strive to meet average standards. For instance, Peschiera et al. integrated social networks with energy consumption feedback, enabling office workers to directly compare electricity usage on a network platform, significantly accelerating the diffusion of energy-saving behaviours (Paone & Bacher, 2018)[12].

Based on this evidence, the design of energy-saving feedback should evolve beyond mere information delivery to encompass a systematic examination of psychological mechanisms throughout the entire human-machine interaction process. Within this context, the cognitive ergonomics branch of human factors engineering provides a robust theoretical analytical framework. This theory emphasises that information system design must fully account for human perception, comprehension, memory, and response load to optimise task efficiency and reduce cognitive fatigue (Kaur & Sharma, 2024) [13]. Consequently, energy-saving feedback design requires comprehensive consideration of human factors such as users' cognitive load, emotional arousal, and attention resource allocation. This ensures systems are not merely “usable” but also “willingly used”, thereby enhancing the effectiveness of energy-saving behaviour conversion.

2.3 The Integration of Dual-System Decision Theory

Building upon human factors engineering's emphasis on optimising cognitive load and system usability, elucidating the underlying psychological mechanisms of behavioural change necessitates invoking dual-system decision theory. This framework posits that behavioural transformation constitutes a transition from habitual, rapid responses (System 1) to rational, deliberate processing (System 2) (Kahneman, 2011) [14]. System 1 represents rapid, intuitive, and emotion-driven automatic response mechanisms, whose psychological mechanism manifests as emotional arousal. System 2, conversely, represents slow, deliberate, and logically reasoned cognitive processing pathways. According to cognitive ergonomics, when information complexity exceeds a user's capacity, cognitive load arises. Excessive cognitive load becomes a behavioural barrier, causing users to abandon rational analysis and negatively impacting energy-saving intentions.

To counteract users' System 1 inertia in energy-saving behaviour, designers can activate System 2 thinking by enhancing the emotional arousal of feedback or inducing cognitive dissonance. For instance, an experiment published in ACM demonstrated that when energy-saving feedback systems integrated ‘caring metaphors’ with generative AI narratives, even users with low environmental awareness exhibited heightened motivation to conserve energy. This feedback approach, combining metaphorical and emotional guidance, successfully shifted users from System 1 inertia to System 2's deeper cognitive pathways (e.g., focusing on “energy-saving outcomes” and “value significance”) (Berney et al., 2024) [2].

Furthermore, to support System 2 activation and sustained engagement, research also explores design approaches that reduce cognitive load and enhance user interest. For instance, employing contextual metaphors and gamified representations-such as ‘virtual energy-saving trees’ or points-based systems-can lower cognitive load through visualisation, personification, and entertainment elements, thereby boosting participation interest. Some literature regards such gamified, artistic visualisation methods as effective means of energy-saving feedback, catering to diverse visual preferences while deepening environmental awareness (Chalal et al., 2022) [15].

3. Method

3.1 Theoretical Linkages Between Feedback Types and Psychological Mechanisms

Drawing on dual-system decision theory, this study examines three representative feedback paradigms currently deployed in office energy management systems: metaphorical, social comparison, and numerical feedback-and investigates how each activates distinct psychological pathways.

Metaphorical Feedback. This approach employs concrete, personified elements ((e.g., virtual growth)) to represent energy consumption. By avoiding complex numerical processing, metaphorical designs engage System 1 directly through emotional and intuitive channels. The objective is to stimulate emotional arousal, thereby activating the "intuition–emotion pathway" to promote energy-saving intentions (Chalal et al., 2022) [15].

Social Comparison Feedback. This approach contrasts a user's energy consumption performance against average levels or"energy-saving role models."By tapping into human instincts for conformity to social norms and competitiveness, it elicits immediate emotional responses (such as pride or shame) (Yagasaki, 2019) [16]. At the same time, the provision of comparative data enables users to reflect rationally on discrepancies between their behaviour and group norms (Cassola et al., 2022) [17], thereby activating System 2 thinking. Consequently, social comparison feedback is regarded as a potent intervention acting upon both cognitive systems.

Numerical feedback presents raw, objective data through formats such as bar charts, line graphs, or numerical values. This type of information requires greater attention and cognitive effort to analyse and interpret (Peters et al., 2006) [18], thereby primarily activating the "rational–cognitive load pathway" associated with System 2. However, overly complex or dense information can impose excessive cognitive load, leading to confusion and frustration. In such cases, users may abandon rational analysis and revert to System 1's habitual behavioural patterns.

3.2 Experimental Design and Variable Definition

This study investigates how feedback design in human-computer interaction influences energy-saving behavioural intentions in office settings through psychological mechanisms. Consequently, a single-factor (feedback type) three-level online scenario experiment design was employed. The study established energy-saving feedback type as the core independent variable, comprising three levels: metaphorical, social comparison, and numerical. The dependent variable was office energy-saving intention, reflecting participants' propensity to adopt energy-saving behaviours after viewing feedback. To examine the mediating mechanisms of dual-system decision theory, two parallel mediating variables were introduced: emotional arousal representing the intuitive-affective pathway (System 1), and cognitive load representing the rational-cognitive load pathway (System 2). All data were collected via an online questionnaire platform, which utilised its built-in random allocation function to evenly assign eligible participants across three experimental groups. This ensured baseline equivalence between groups and internal validity of the experiment.

3.3 Experimental Stimuli Design

This study designed a simulated interface for office energy consumption management, comprising three distinct feedback interface prototypes:

Metaphorical Interface: As illustrated in Figure 1, a 'virtual plant' was designed: thriving when users conserve energy and withering when energy is wasted. Accompanied by concise textual prompts, it guides users' attention towards their energy usage behaviour.

Social Comparison Interface: As illustrated in Figure 2, this provides users with energy consumption comparisons against a reference group (departmental average). The interface displays the user's current electricity usage ranking within the group via bar charts or graded badges, accompanied by prompts such as 'X% above/below average' to stimulate competitive and conformist tendencies.

Numerical Interface: As shown in Figure 3, this directly displays real-time energy consumption data and target progress. For instance, it quantifies daily electricity usage numerically, providing corresponding energy-saving targets or historical averages for reference, while illustrating trends through simple charts.

All three interfaces undergo professional visual design to ensure consistency in layout, colour scheme, and information density. Differences lie solely in the presentation of core feedback information, thereby maximising isolation from variable influences.

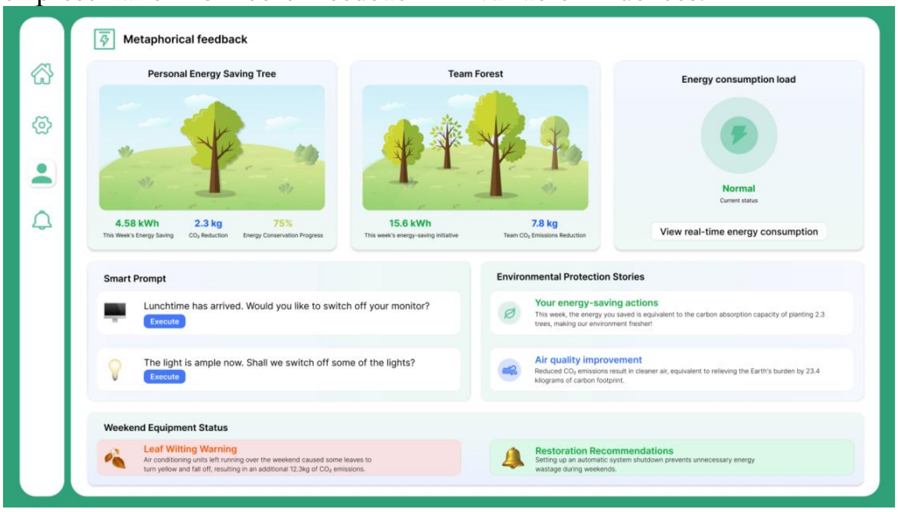

Figure 1. Metaphorical Feedback Interface

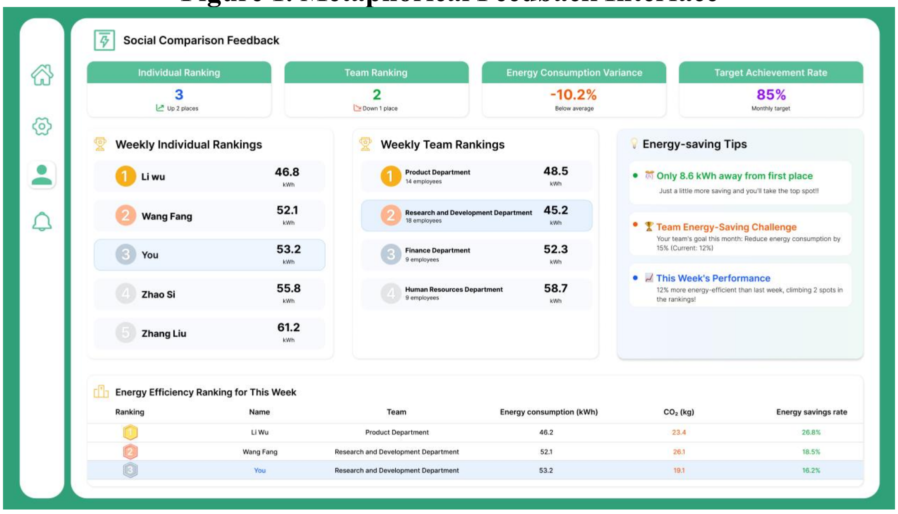

Figure 2. Social Comparison Feedback Interface

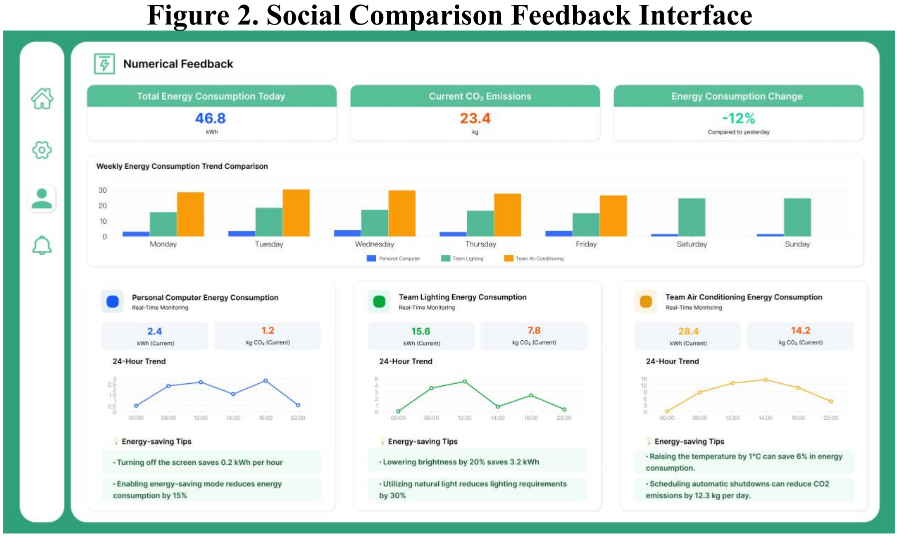

Figure 3. Numerical Feedback Interface

3.4 Experimental Procedures and Questionnaire Measurement Tools

The entire experimental procedure was conducted via a scenario-simulation utilizing a single-factor experimental design, executed through the following sequential steps:

Participants first reviewed the study objectives and an informed consent form. Eligibility was restricted to individuals aged 18 or over. Consent was confirmed for the voluntary use of their anonymized data for research purposes.

All participants viewed a standardised ‘Energy Management System Main Interface Example’ (depicted in Figure 4). This interface simulated a real office environment, displaying comprehensive metrics such as overall energy efficiency, carbon reduction, and cost savings, alongside individual and team energy consumption details. Its purpose was to establish a shared contextual understanding among all subjects, ensuring a consistent foundation before exposure to different feedback conditions and thereby guaranteeing the comparability and validity of experimental results.

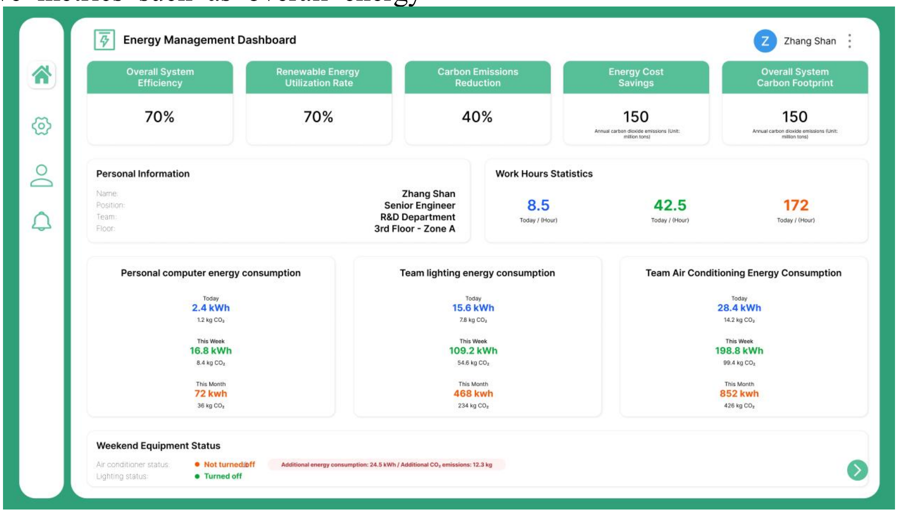

Figure 4. Example Energy Management System Main Interface

Participants were randomly assigned to one of three experimental groups (Numerical, Social Comparison, Metaphorical). Each participant viewed only the unique feedback interface stimulus (Figures 1, 2, or 3) corresponding to their assigned group. Participants were instructed to carefully observe the interface and imagine themselves using it in their daily office work.

Attention check questions were implemented prior to formal measurement to ensure participants had thoroughly read the screen content.

Participants completed all questionnaire items sequentially based on their interface viewing experience:

The dependent variable was employee energy-saving intention, measured using a commonly employed self-report scale designed for behavioural intention toward pro-environmental actions within environmental psychology. Five items measure participants' propensity to undertake energy-saving behaviours within the coming week, such as ‘proactively switching off unnecessary office equipment’ and ‘setting air conditioning temperatures to more energy-efficient levels’. These items employ a 7-point Likert scale (1 = Strongly Disagree, 7 = Strongly Agree), with the mean score representing the intensity of energy-saving intention. Mediating variable 1 is emotional arousal, measured using a scale adapted from (Thompson, 2007) [19]. Five items assess users' feelings when interacting with the interface, such as ‘feeling energetic,’ ‘excited,’ or ‘pleased.’ Higher scores indicate stronger positive emotional arousal elicited by the feedback interface. Mediating variable 2 is cognitive load, assessed via six items evaluating subjective mental strain. The scale references (Hart & Staveland, 1988) and includes items such as ‘mental demands,’ ‘time pressure,’ ‘effort level,’ ‘frustration,’ and ‘overall load.’ The ‘performance satisfaction’ item is reverse-scored. Also rated on a 7-point scale, higher scores indicate users perceive a heavier burden in comprehending information. The questionnaire further includes participants' basic demographic information and subjective evaluations of the interface.

Following the collection of necessary socio-demographic information, the experiment concluded.

3.5 Data Analysis

Data collected in this study were systematically analyzed using IBM SPSS Statistics 31 and the PROCESS macro (v4.2) developed by Hayes

('An Index and Test of Linear Moderated Mediation', 2025) [20].

First, internal consistency reliability was assessed for each measurement scale employed in the study by calculating Cronbach's Alpha (α) coefficients. Subsequently, to test Hypothesis 1-comparing the effects of different feedback types on "energy-saving intention"-a one-way analysis of variance (ANOVA) was employed to examine whether significant differences existed in the mean "energy-saving intention" scores across the three feedback types.

To test the hypothesized dual-mediating mechanisms (Hypothesis 2), the PROCESS macro for SPSS (Model 4), as recommended by Hayes (2018), was utilized. The categorical independent variable (feedback type) was entered as a multicategorical variable and converted into dummy variables for analysis. The Numerical feedback type was designated as the reference group, with the Metaphorical and Social Comparison groups compared against it. Affect Arousal and Cognitive Load served as the parallel mediating variables, and Energy-Saving Intention was the dependent variable.

The significance of the indirect (mediation) effects was determined using a bias-corrected bootstrap procedure based on 5,000 resamples. A significant indirect effect was established if the 95% confidence interval (CI) did not contain zero. All statistical tests were conducted using a two-tailed test with a significance level set at $\alpha=0.05$.

4. Results

4.1 Descriptive Statistical Analysis

This study conducted descriptive statistics and reliability analysis on three primary variables, with a total sample size of 299. As shown in Table 1, the mean values for all three variables fell within the medium-to-high range of the scales, indicating that respondents held an overall positive attitude towards their experience of energy-saving feedback and their energy-saving intentions. Regarding reliability analysis, all scales demonstrated good internal consistency. Cronbach's α coefficients for each variable exceeded 0.69. Energy-saving intention ($\alpha=0.767$) met the criterion for good reliability; emotional arousal ($\alpha=0.713$) demonstrated acceptable reliability; and cognitive load ($\alpha=0.699$) approached acceptable reliability. Overall, the internal consistency of the scales demonstrated satisfaction with psychometric requirements, establishing a reliable foundation for subsequent inferential statistical analyses.

Table 1. Descriptive Statistics and Reliability Analysis of Key Variables

Variable	Mean	Standard Deviation (SD)	Cronbach's α
Emotional Arousal	5.214	0.903	0.713
Cognitive Load	4.302	0.884	0.699
Energy-Saving Intention	5.916	0.738	0.767

4.2 Hypothesis 1: Results of One-Way Analysis of Variance (ANOVA)

A one-way analysis of variance (ANOVA) was conducted to examine whether energy-savinintentions differed across the three feedback conditions (numerical, social comparison, and metaphorical). Levene's test for homogeneity of variances was non-significant ($p = 0.957 > 0.05$), confirming that the assumption of equal variances was met. Accordingly, a conventional one-way ANOVA and Tukey's post-hoc comparisons were employed for inference.

One-way ANOVA Results Table 2 shows that the overall difference in energy-saving intentions across feedback types was not significant, $F(2, 296) = 0.374$, $p = 0.688$. The effect size was extremely small (biased $\eta^2 = 0.003$, 95% CI [0.000, 0.020]), indicating negligible between-group differences. This suggests that the three feedback formats did not elicit differing levels of energy-saving intention.

Table 2. One-Way ANOVA Summary for Energy-Saving Intention

Source	SS	df	MS	F	p	η²
Between Groups	0.409	2	0.205	0.374	0.688	0.003
Within Groups	161.293	296	0.545			
Total	162.356	298				

Note. SS = Sum of Squares; df = Degrees of Freedom; MS = Mean Square;

F= statistic of one-way analysis of variance (ANOVA);

η^2= Partial Eta Squared (Effect Size).

As shown in the descriptive statistics Table 3, the group means were highly similar, indicating that the average levels of energy-saving intention were nearly identical across all three groups: numerical feedback (M = 5.961, SD = 0.714), social comparison feedback (M = 5.871, SD = 0.747), and metaphorical feedback (M = 5.914, SD = 0.728).

Table 3. Descriptive Statistics of Energy-Saving Intention by Feedback Type

Feedback Type	Code Name	N	Mean	Standard Deviation
Numerical	1	102	5.961	0.714
Social Comparison	2	97	5.871	0.747
Metaphorical	3	100	5.914	0.728

Tukey's HSD post-hoc analysis confirmed, as shown in Table 4, that all pairwise differences were non-significant (all ps > 0.65), with between-group mean differences falling below 0.10.

Table 4. Tukey's HSD Post-Hoc Comparisons of Energy-Saving Intention

Pairwise Comparison	Mean Difference	Standard Error	p (Tukey HSD)	95% CI Lower Bound	95% CI Upper Bound
1 vs 2	0.09068	0.1049	0.663	-0.1564	0.3378
1 vs 3	0.04678	0.10364	0.895	-0.2915	0.1979
2 vs 3	-0.0439	0.10726	0.912	-0.2972	0.2094

Note. The group codes are:
1 = Numerical Feedback;
2 = Social Comparison Feedback;
3 = Metaphorical Feedback.

Combining these findings indicates that the feedback type itself did not directly alter participants' reported energy-saving intentions. The minuscule effect size ($\eta^2 = 0.003$, 95% CI [0, 0.020]) further corroborates that observed between-group differences were negligible. This finding underscores the need to examine potential psychological mechanisms-such as emotional arousal and cognitive load-as possible mediators of how feedback influences energy-saving behaviour, which will be discussed in subsequent analyses.

To examine whether the influence of feedback type on energy-saving intentions follows the dual-system decision theory pathway, this study employed the PROCESS v4.2 parallel mediation model (Model 4). The independent variable was the categorical feedback type (X), energy-saving intention (Y) as the dependent variable, and emotional arousal (M1) and cognitive load (M2) as multiple mediating variables. Numerical feedback (Group 1) was designated as the reference group, with social comparison feedback (X1) and metaphorical feedback (X2) serving as comparison groups for analysis. Mediating effects were tested using the Bootstrap method (5,000 repeated samples). The mediation analysis results are presented in Table 5.

4.3 Hypothesis 2: Mediating Effects Results

Table 5. Results of the Mediation Analysis (Path Coefficients)

path	Variable	outcome variable	coefficient	SE	t	p	LLCI	ULCI
a	X1	Emotional Arousal	0.2923	0.1273	2.2958	0.0224	0.0417	0.5429
a'	X2	Emotional Arousal	0.1474	0.1263	1.1668	0.2442	-0.1012	0.396
b	X1	Cognitive Load	0.0375	0.1255	0.2986	0.7655	-0.2095	0.2844
b'	X2	Cognitive Load	-0.1101	0.1245	-0.8845	0.3771	-0.3552	0.1349
c	Emotional Arousal	Energy-Saving Intention	0.3431	0.0478	7.1807	0	0.2491	0.4372
c'	Cognitive Load	Energy-Saving Intention	-0.1156	0.0485	-2.3847	0.0177	-0.2111	-0.0202

Note. X1 = Social comparison vs Numeric condition ; X2 = Metaphor vs Numeric condition LLCI = Lower Limit of the 95% Confidence Interval; ULCI = Upper Limit of the 95% Confidence Interval.

Firstly, regarding the "intuition-emotion pathway", the regression analysis indicated that emotional arousal significantly and positively predicted energy-saving intention ($b = 0.3431$, $p < 0.001$). This finding supports the hypothesis that higher emotional arousal enhances participants' intentions to engage in energy-saving behavior.

Further analysis examined how feedback type influenced the activation of these mediating pathways. Using numerical feedback as the baseline group, results showed that metaphorical feedback did not significantly predict emotional arousal ($b = 0.1474$, $p = 0.2442$), indicating no reliable difference relative to the baseline.

When assessing the effect of feedback type on cognitive load, neither social comparison ($b = 0.0375$, $p = 0.7655$) nor metaphorical feedback ($b = -0.1101$, $p = 0.3771$) produced significant effects. These findings suggest that feedback type did not reliably alter participants' subjective cognitive load under the present experimental conditions.

Subsequently, a bootstrap procedure with 5,000 iterations was employed to assess the indirect effects of feedback type on energy-saving intention as shown in Table 6, with both social comparison and metaphorical feedback evaluated relative to numerical feedback. For the pathway mediated by emotional arousal (intuition–emotion pathway), only the social comparison feedback showed a statistically significant indirect effect through emotional arousal, with an indirect effect value of 0.1003 and a 95% confidence interval of [0.0147, 0.1921]. The indirect effect of metaphorical feedback was not significant (95% CI included zero).

Table 6. Indirect Effects Analysis (Bootstrapping Results)

Comparison	Mediation Path	Indirect Effect	Boot SE	Boot LLCI	BootULCI	Upper Diff (+)	Lower Diff (–)
X1	Via Emotional Arousal	0.1003	0.0446	0.0147	0.1921	0.0918	0.0856
X2	Via Emotional Arousal	0.0506	0.0451	-0.0402	0.1373	0.0867	0.0908
X1	Via Cognitive Load	-0.0043	0.0157	-0.0398	0.0261	0.0304	0.0355
X2	Via Cognitive Load	0.0127	0.0161	-0.0162	0.0484	0.0357	0.0289

Note. X1 = Social comparison vs Numeric condition; X2 = Metaphor vs Numeric condition

In the indirect effect pathway via cognitive load (rationality–cognitive load), since feedback type failed to significantly manipulate cognitive load, neither type of feedback (compared to numerical feedback) produced statistically significant indirect effects through cognitive load.

The combined findings provide strong support for the dual-system decision theory's joint mediation hypothesis, with effect directions fully aligning with theoretical predictions: emotional arousal exerts a significant positive influence on self-control intention (intuition-emotion pathway), while cognitive load manifests as a significant negative influence (rationality-cognitive load pathway). However, at the level of feedback mechanism activation, the analysis revealed partial dominance of the “intuition-emotion pathway”: only social comparison feedback significantly enhanced emotional arousal compared to numerical feedback, thereby generating a significant positive indirect effect, whereas metaphorical feedback failed to activate this mechanism. Notably, neither feedback type significantly influenced cognitive load, rendering the rational pathway's indirect effect via cognitive load non-existent. This indicates that social comparison enhances intentions by effectively leveraging recipients' emotional responses, whereas the “rational-cognitive load pathway” was not effectively activated within this study's context. Consequently, future research should focus on optimising the presentation of metaphorical or numerical information by adjusting task difficulty, information complexity, or accounting for individual working memory sensitivity. This will explore the potential for successfully triggering and utilising the cognitive load pathway.

5. Conclusion

This study, grounded in dual-system decision theory, systematically examined the influence mechanisms of three ecological feedback interfaces-numerical, social comparison, and metaphorical-on office workers' energy-saving intentions. The findings robustly confirm that in designing energy-saving feedback for offices, emotional arousal serves as the key driver promoting intentions, while cognitive load constitutes a significant barrier inhibiting them.

The analyses revealed that social comparison feedback uniquely activated the emotional arousal pathway, producing a significant positive indirect effect. This outcome is consistent with social psychological theory: social comparison mechanisms elicit immediate and salient emotional responses concerning perceived performance superiority or inferiority (e.g., pride in outperforming peers or shame in falling below average).) By directly linking individual energy consumption to group norms or competitors. This emotional force proves particularly potent within the collective action context of office settings, effectively circumventing users' cognitive inertia regarding energy expenditure behaviours. It stimulates initial attention and motivation, thereby driving rational evaluation (System 2) or directly influencing behavioural intent.

By contrast, while metaphorical representations are visually approachable, they did not significantly enhance emotional arousal. This suggests their affective intensity may be insufficient to disrupt System 1 inertia. Future enhancements could employ more emotionally resonant metaphors or narratives incorporating moderately negative consequences. Although the cognitive load pathway holds directional validity, the differential impact of feedback types was not statistically significant. This may stem from the clear information design of stimuli in this study failing to reach load thresholds, coupled with the limited sensitivity of the NASA-TLX scale in static scenarios. Subsequent research should employ stronger or more refined manipulations. Examples include increasing task difficulty, introducing time pressure, implementing personalised presentations based on individual working memory, and conducting longitudinal tracking in real office environments.

Finally, this study innovatively integrates interface design elements from HCI with psychological decision models to construct and validate a three-stage causal model: 'feedback type – psychological mechanism – behavioural intention'. This framework addresses previous energy-saving feedback research's neglect of users' internal response processes, offering a novel theoretical perspective on how different interaction designs influence user behaviour. At the practical level, the study recommends prioritising the introduction of socially comparative mechanisms reinforced by positive emotions, coupled with simplified and hierarchical information presentation to manage cognitive load. This approach is expected to more effectively translate energy-saving motivation into action. Long-term tracking experiments in authentic office settings are further proposed to validate the model's sustained efficacy and universal applicability.

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