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Short- and long-term ecological consequences of methodological discrepancies in building energy efficiency calculations

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Abstract. In the context of global decarbonisation, the accuracy of assessing building energy efficiency has become a critical factor for predicting environmental impacts and achieving vital climate goals. Existing discrepancies between national and international calculation methodologies have created significant risks during the planning of large-scale thermal modernisation strategies. This article aimed to quantitatively assess the ecological consequences of methodological discrepancies between quasi-stationary and hourly dynamic approaches to calculating building energy consumption. A comprehensive approach was developed, including hierarchical modelling and a detailed methodology for converting energy consumption into carbon emission mass with a thorough assessment. It was established that the key sources of methodological discrepancy are the choice of the time model, the format of presenting climatic data, the description of thermal inertia, and the algorithm for interpreting internal heat gains. Research proved that the difference in annual energy demand when changing calculation methods reaches several tens of percent. This was equivalent to deviations in carbon dioxide emission mass in the range of hundreds of kilograms. To address this, the concept of a "zone of discrepancy" was proposed, introducing a threshold T to determine the feasibility of using simplified methodologies depending on the required accuracy. A methodology for aggregating individual deviations to the building stock level, based on a deterministic comparison of representative scenarios, is justified. These mathematical dependencies for quantitative assessment increase environmental

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monitoring reliability, allowing specialists to develop precise regulatory requirements and reduce the construction sector's carbon footprint

Keywords: decarbonisation; thermal modernisation; carbon footprint; fuel and energy resources; regulatory framework; dynamic modelling

Introduction

Improving building energy efficiency is a key decarbonisation tool, but the accuracy of assessing the environmental load critically depends on the chosen energy demand calculation model. The use of different methodological approaches when harmonising national and international standards causes significant discrepancies in determining the annual volumes of pollutant emissions. In the long term, such methodological uncertainty accumulates, leading to systemic distortions in predicting environmental effects at the level of the entire building stock. Consequently, a quantitative analysis of the consequences of applying different methodologies is necessary for the formation of optimal energy modernisation strategies and ensuring the sustainable development of the sector.

The problem of methodological differences in building energy efficiency calculations has been studied by numerous scientists. The existing scientific heritage has outlined both the theoretical foundations of calculation models and applied approaches to assessing energy consumption and related ecological consequences. A number of studies emphasised that the key discrepancy between Ukrainian (DSTU) and international (ISO/EN) approaches lies in different approximations of time characteristics (quasi-stationary monthly models versus hourly dynamic models) which, as I.M. Dashko & D.V. Krylov (2021) pointed out, stems from fundamentally different approaches to the assessment of enclosing structures, engineering systems, and operational features. This difference is clearly observed when comparing DSTU 9190:2022 (2022) with the international standard ISO 52016-1:2017 (2017), moreover, the international normative document provides a more accurate dynamic approach and allows accounting for hourly temperature fluctuations, solar radiation, and the inertial properties of building masses.

The practical consequences of such methodological differences result in differing calculation outcomes, which can lead to incorrect classification of the building's energy class, erroneous ranking of thermal modernisation measures, and making unjustified investment decisions. O.V. Komelina & A.A. Komelina (2022) argued that the lack of methodology unification complicates data integration and distorts the assessment of environmental risks at the national level, which is critical for achieving climate goals. At the same time, T.D. Kosova & A.D. Titarenko (2021) were confident that for Ukraine, the problem of improving the legislative framework and finding effective financial incentives is critically relevant. The current regulations often do not meet modern international standards, and business support mechanisms, such as tax benefits and lending, are insufficiently effective and limited. The absence of adequate incentives hinders investments in energy-saving technologies and restrains the development of the relevant market. H. Farenyuk & Ye. Farenyuk (2025) also noted a pragmatic approach: quasi-stationary methods (embedded in individual DSTUs or national codes) are recognised as justified for mass screening and rapid design, whereas hourly dynamic models according to ISO 52016-1 are appropriate for detailed engineering analysis and complex operating modes. Accordingly, such a dichotomy highlights the need for formalised criteria for choosing a methodology depending on the calculation purpose, project scale, and expected accuracy.

Considering the above, the current scientific discussion focuses on three interrelated areas: refinement and unification of input data and assumptions to ensure comparability; development of procedures for selecting an adequate methodology for specific classes of objects; quantitative assessment of the impact of methodological discrepancies on environmental indicators (in particular, predicted emission volumes) and the economic feasibility of energy modernisation. Accordingly, further research should be aimed at developing practically oriented tools for harmonising methodologies (including recommendations on applying simplified or detailed approaches) and formalising procedures for recalculating indicators between different approaches in order to correctly assess the ecological consequences of energy efficiency measures. The aim of the study was to quantitatively assess the short- and long-term ecological consequences of methodological discrepancies between quasi-stationary and hourly dynamic approaches to calculating building energy efficiency, as well as to identify the key factors causing these differences.

Materials and Methods

Representative types of building premises were used as calculation materials: a residential apartment, an office, and an educational classroom. They were purposefully selected according to criteria of typicality, prevalence in the building stock, and differences in functional purpose, allowing for a comparison of results for objects with different thermal load profiles. The choice of materials was determined by their availability, regulatory validity, and suitability for comparing results obtained using different calculation methodologies. To demonstrate the application of the proposed approach, three representative building types (a residential apartment, an office, and a classroom) were selected as illustrative cases for visualisation and aggregation. A set of simplified scenarios was developed to

estimate greenhouse gas emissions using emission factors (*EF*), with the corresponding coefficients adopted from the Green Transition Office database (Shlapak *et al*., 2024). For the residential case study, annual energy demand was calculated using two alternative methodologies: ISO 52016-1:2017 (2017) and DSTU 9190:2022 (2022). The annual energy demand of a typical apartment was estimated at 17,200 kWh according to DSTU 9190 and 12,717 kWh according to ISO 52016-1. The difference between the calculated values was determined as:

$$\Delta Q = QDSTU - QISO = 4{,}483\ kWh.$$

The relative deviation between the methods was calculated as a percentage of the ISO-based estimate. To assess the environmental implications of methodological differences, the obtained energy demand deviation was converted into CO_2 emissions using the natural gas emission factor ($EFgas$ = 0.201 kg CO_2/kWh) reported by M. Shlapak *et al*. (2024). The resulting difference in annual emissions was calculated according to the following equation:

$$\Delta mCO_2 = \Delta Q \times EFgas, \quad (1)$$

where ΔmCO_2 – the difference in annual CO_2 emissions (kg/year); ΔQ – the difference in calculated annual energy demand (kWh/year); $EFgas$ – the natural gas emission factor (kg CO_2/kWh).

The theoretical basis of the article was based on combining a formal dynamic energy balance model as a basic description of the physical process; a comparative analysis of DSTU and ISO/EN standards, as well as evaluating the differences between the results of quasi-stationary and hourly dynamic approaches and practical implementation through modelling to develop rules for recalculating results between methodologies. The methodological framework combined the formalisation of physical building energy balance models with a clear procedure for converting energy results into environmental indicators and quantitatively assessing the uncertainty of such conversions.

According to S.B. Smereka & S.M. Lifyrenko (2025) two complementary classes of energy demand calculations are fundamental: quasi-stationary (monthly, as in national methodologies according to DSTU) and hourly dynamic (ISO 52016-1). Based on them, a sequential chain of transformations was formed: formalisation of energy calculation → linear conversion of energy into emissions → aggregation by energy carrier classes and equipment → analysis of the "zone of discrepancy" in environmental impact indicators → study of consequences in the context of the building stock. To perform the comparative analysis, normative-methodological documents regulating the calculation of building energy efficiency in Ukraine and internationally were used, namely ISO 52016-1:2017 (2017), DBN V.2.6-31:2021 (2021), and DSTU 9190:2022 (2022). To convert energy consumption into greenhouse gas emissions, emission factors listed in open official and reference sources were applied. According to DBN V.2.6-31 (2021), building energy efficiency calculations are based on formalised mathematical models of energy balance, where the key components are temporal climate characteristics, internal heat gains, parameters of enclosing structures, and operating modes of engineering systems. In its basic form, the dynamic energy balance is described by a differential equation of the form:

$$C_{int} \cdot \frac{d\theta_{int}(t)}{dt} = \Phi_{tot}(t), \quad (2)$$

where C_{int} – the effective heat capacity of the building; $\frac{d\theta_{int}(t)}{dt}$ – the time derivative of the internal temperature; $\Phi_{tot}(t)$ – the sum of all heat fluxes at time t.

The formalisation of the energy calculation consists in selecting input data and typical objects – a set of parameters and scenarios necessary for the a priori systematisation of the physical model, so this stage prepares the tools and initial data for the further implementation of calculation procedures. Without a clear description of the geometry, thermal characteristics, and climatic profiles, it is impossible to correctly apply either the monthly or the hourly algorithm. The indicator $\Phi_{tot}(t)$ from formula 1 can be detailed. Then the general dynamic energy balance equation takes the form:

$$C_{int} \cdot \frac{d\theta_{int}(t)}{dt} = \Phi_{HC}(t) + \Phi_{int}(t) + \Phi_{sol}(t) - \\ - H_T \cdot [\theta_{int}(t) - \theta_e(t)] - H_V \cdot [\theta_{int}(t) - \theta_e(t)], \quad (3)$$

where $\Phi_{HC}(t)$ – the heat flux from heating and cooling systems; $\Phi_{int}(t)$ – internal heat gains; $\Phi_{sol}(t)$ – solar gains; H_T – the transmission heat transfer coefficient of the enclosures; H_V – the ventilation heat loss coefficient; $\theta_{int}(t)$ – the internal temperature at time t; $\theta_e(t)$ – the external temperature at the same moment.

To transition from the instantaneous energy balance described by equations 1-2 to the annual energy demand indicator, integration of the thermal load over the calculation period was used. For the quasi-stationary methodology, this period corresponded to the heating year, and the annual energy demand was determined as the sum (integral) of the time values of the heat flux over the entire calculation interval. In the hourly dynamic model, integration was performed with a time step of 1 hour, which allowed accounting for the diurnal variability of climatic conditions, internal gains, and the operation of engineering systems. Formally, the annual energy demand was determined as the integral of the thermal load over the period $0 \le t \le T$, where T is the duration of the calculation year or heating season depending on the methodology. The difference in temporal discretisation and the duration of the calculation period is one of the key sources of discrepancy between the results of DSTU- and ISO-oriented approaches:

$$E_p = \sum_{k=1}^{N} \Phi_{tot}(t_k)\Delta t,\ \Delta t = 1 \text{ hour}. \quad (4)$$

After implementing both types of calculations (monthly and hourly), it is necessary to obtain numerical values

of energy demand E in comparable units (hourly, seasonal, annual). It is these results that form the basis for further linear and advanced transformations into environmental indicators: only by having comparable E values is it possible to apply primary energy coefficients α and emission factors EF to obtain the emission mass. The standard operational approximation for converting energy consumption into CO_2 emission mass has a linear form:

$$m_{CO_2} = E \cdot EF, \quad (5)$$

where E – the annual amount of energy to be recalculated (kWh); EF – the emission factor (kg CO_2/kWh) for the corresponding energy carrier or generating unit. It is important to distinguish the types of the indicator E: consumed final energy E_{cons}; primary energy E_p; system heat output E_{heat}. The dependencies between them can be presented linearly:

$$E_p = \alpha \cdot E_{cons}; \quad (6)$$

$$m_{CO_2} = E_p \cdot EF_p = E_{cons} \cdot (\alpha \cdot EF_p), \quad (7)$$

where α – the conversion factor to primary energy; EF_p – the emission factor calculated per primary energy. The result of this stage are numerical bases that can be transformed into emission mass indicators.

At the stage of aggregation by energy carrier classes and equipment, it is necessary to foresee the breakdown of the emission mass into components by sources:

$$m_{CO_2}^{(tot)} = \sum_j E_{cons}^{(j)} \cdot \alpha^{(j)} \cdot EF_p^{(j)}, \quad (8)$$

where the index j – the type of energy carrier or generation method (gas boiler, centralised heat, electrical grid with a specific generation component, etc.). This will make it possible to assess the sensitivity of the output result to changes in the energy supply structure (for example, replacing a gas boiler with a heat pump or changing the power grid to photovoltaic generation). The choice of matrices $EF_p^{(j)}$ and $\alpha^{(j)}$ should be made based on the information provided in the methodological guidelines and national normative documents.

The initial construct was the explicit representation of an individual deviation in the mass of greenhouse emissions due to the methodological choice: for each unit of the stock i the value is introduced:

$$\Delta m_i = (E_{DSTU,i} - E_{ISO,i}) \cdot EF_i, \quad (9)$$

which underscores the dual nature of the problem – the combination of a methodological discrepancy in assessing energy demand and the variability of the emission intensity of the heat supply source. The cumulative effect was determined by the sum of individual deviations:

$$\Delta M = \sum_{i-1}^{N} \Delta m_i. \quad (10)$$

This formula reflects the deterministic core of aggregation. The concept of the "zone of discrepancy" is formalised. In other words, knowing which sources of uncertainty dominate allows determining the criteria for selecting the threshold T and for constructing a rule for the parameter's inclusion in the zone of discrepancy. As a criterion for defining the zone of discrepancy, a pragmatic threshold T is introduced (for example, T = 10% relative to the annual heat demand). The set of parameters x (climate, U-values, C_{int}, occupancy profile, etc.) for which the condition is met:

$$\left|\frac{E_{DSTU}(x) - E_{ISO}(x)}{E_{ISO}(x)}\right| \geq T, \quad (11)$$

defines the zone of discrepancy. The translation of this criterion to the ecological scale is carried out through the corresponding EF, meaning the zone of discrepancy generates a set of scenarios with a deviation in emission mass:

$$\Delta m_{CO_2}(x) = (E_{DSTU}(x) - E_{ISO}(x)) \cdot EF(x). \quad (12)$$

Quantitative localisation of such zones can be performed using parametric scanning, followed by building "parameter/climate" heat maps. Implementing this approach allows formulating practical rules: provided it falls within the zone of discrepancy, using a quasi-stationary methodology is considered inappropriate for the purpose of environmental assessment. Once the zone of discrepancy is defined and localised in the parameter space, the next logical step is to assess its consequences at a higher aggregation level: at the building stock level. Information about the share of buildings falling into the zone of discrepancy and the magnitudes of individual deviations Δm_{CO_2} allows transitioning from individual cases to assessments of the cumulative impact on the municipal or national building stock. The cumulative effect is estimated as the sum of individual deviations over the number of buildings:

$$\Delta M_{CO_2}^{(tot)} = \sum_{i-1}^{N} (E_{DSTU,i} - E_{ISO,i}) \cdot EF_i. \quad (13)$$

In practical application, N is formed taking into account typology, distribution of technical characteristics, and the frequency of distinct building classes. This approach allows modelling short- (1-5 years) and long-term (10-30 years) scenarios of the impact of choosing the methodology for calculating energy efficiency indicators on the volume of emissions. The temporal dynamics of aggregation are introduced via the time parameter t, which allows formalising the integral effect over the forecast horizon T:

$$\Delta M_{[0,T]} = \sum_i \int_0^T (E_{DSTU,i}(t) - E_{ISO,i}(t)) \cdot EF_i(t) dt. \quad (14)$$

Formula 14 was used in the study as a general scenario dependency for evaluating the accumulated effect over the forecast horizon T. Since the actual calculations within the research were performed for one year, the annual value is taken as the basic step for extrapolation over a longer period. For this transition, it is assumed that the

annual difference between the methodologies remains constant over time, and the structure of energy consumption and emission factors do not change. Accordingly, for a representative group of three types of objects, the total annual deviation is 3,754.28 kg CO_2/year for natural gas, 7,527.24 kg CO_2/year for centralised heat supply, and 8,108.94 kg CO_2/year for electricity supply, which over 10 years corresponds to values of 37,542.8; 75,272.4, and 81,089.4 kg CO_2, respectively, over 20 years – 75,085.6; 150,544.8, and 162,178.8 kg CO_2, and over 30 years – 112,628.4; 225,817.2, and 243,268.2 kg CO_2. Thus, even under the conservative assumption about the constancy of the annual difference, the methodological effect accumulates into very significant quantities over the medium- and long-term planning horizons. The quantitative analysis within this study had a deterministic comparative nature and was aimed at juxtaposing the results obtained using quasi-stationary and hourly dynamic methodologies. The assessment was performed by calculating the absolute and relative deviations between the annual energy demand values and corresponding CO_2 emissions for representative scenarios. Therefore, the results presented below should be interpreted as deterministic scenario estimates obtained for typical objects and fixed emission factors.

Results

The energy efficiency of buildings and structures is a fundamental factor in ensuring the energy security, sustainable development, and economic growth of Ukraine. It is recognised as a key priority at the current stage of development, encompassing both national economies and individual structures. This is driven by the strategic need to respond to global limitations – the depletion of natural non-renewable energy resources. From a technological point of view, energy efficiency is viewed as a consequence of the implementation of modern technologies and equipment that make it possible to reduce the volume of energy required to produce goods and provide services. Within the framework of the economic approach, energy efficiency is treated as the economic expediency of reducing energy consumption volumes. It manifests itself in a reduction of energy costs per unit of GDP or for the production of goods and provision of services (Sovacool & Griffiths, 2020). In the context of ecology, energy efficiency is one of the key mechanisms for minimising the anthropogenic load on the environment, achieved by limiting greenhouse gas emissions and reducing the consumption of non-renewable energy resources (Hossin *et al*., 2023). The interdisciplinary approach to energy efficiency defined it as a generalised complex indicator combining economic, technological, and environmental dimensions of energy resource utilisation processes.

N. Kryshtof (2017) emphasised that building energy efficiency serves as an effective mechanism for ensuring energy security and the structural modernisation of the economy, which in turn requires precise and unified calculation approaches. A. Menegaki (2014) emphasised that improving the energy efficiency of buildings simultaneously solves several tasks: reduces greenhouse gas emissions, lowers household energy poverty, increases energy security, and creates new jobs in the construction and renovation sector. In practical terms, this means transitioning to the deep renovation of existing buildings, modernisation of heating and ventilation systems, comprehensive insulation of facades and roofs, replacement of windows, and implementation of automation and energy management systems. The Commission, forming policy in the field of energy consumption, highlights that buildings are the largest energy consumer in the EU and at the same time possess the greatest potential for reducing final consumption without losing comfort, which warrants special attention to energy efficiency as a strategic priority for the period up to 2050.

According to A. Bahaterenko *et al*. (2013) currently, the real estate sector in Ukraine consumes about 40% of all energy, while a significant part of it is lost due to the use of outdated construction and exploitation technologies. The vast majority of the residential and public building stock is characterised by a low level of thermal insulation and the inefficiency of heating and ventilation systems, leading to excessively high costs for energy resources. The situation has also been complicated by military hostilities, which have significantly damaged the country's energy infrastructure, causing systemic interruptions in the supply of gas, electricity, and heat. Thus, the regulatory and legal field of the study at the level of Ukraine is represented by the respective DSTUs, in particular DSTU 9190 (2022), whereas the international methodology is represented by the ISO 52016-1:2017 (2017). The discrepancies between the DSTU and ISO approaches have a systemic character and are caused by differences in assumptions, model structure, and the interpretation of input parameters. This provision explains why indicators identical in name can be "incomparable values" in a direct comparison without methodological correction.

Specific sources of methodological discrepancy include: the choice of the time model (monthly averaged versus hourly with a 1-hour step), the format of climatic data (average monthly temperatures versus hourly profiles), different approaches to describing the thermal inertia of a building (effective heat capacities of different aggregation levels), the discretisation and logic of heating/cooling systems operation (set-points, time schedules), and the interpretation of internal gains and solar gains. Thus, for the very same object, applying the DSTU and ISO methodologies can yield significantly different values of the annual heat demand and, accordingly, different estimates of operational emissions. According to M. Shovkalyuk (2018), special attention in the development of state stimulation programs must be given to the correct assessment of energy indicators. The absence of adequate baseline calculations can lead to systemic errors when justifying investments in energy efficiency improvements at the municipal level. Based on similarity, a representative sample was created for different premises. It is presented in Table 1.

Table 1. Annual energy demand (kWh)

	Q_{DSTU}, kWh	Q_{ISO}, kWh	ΔQ, kWh	Δ% (Q_{ISO})
Residential apartment	17,200	12,717	4,483	35.3%
Average office room	32,000	24,271	7,729	31.8%
Educational classroom	25,000	18,534	6,466	34.9%

Source: developed by the authors

It is important to emphasise that the given values are the result of deterministic scenario comparisons and do not contain statistical characteristics of variability. Consequently, these data are used to illustrate the systematic difference between calculation methodologies, and not for assessing the probabilistic distribution of outcomes (Table 2).

Table 2. Ecological indicators of emission conversion

	ΔQ	$\Delta m_{CO_2}(gas), kg$	$\Delta m_{CO_2}(ch), kg^*$ *ch – central heating	$\Delta m_{CO_2}(electr), kg$
conversion factor		0.201	0.403	0.430
Residential apartment	4,483	901.08	1,806.65	1,927.69
Average office room	7,729	1,553.53	3,114.79	3,323.47
Educational classroom	6,466	1,299.67	2,605.80	2,857.78

Source: developed by the authors

Accordingly, for all three cases, the emissions associated with central heating and electricity supply approximately doubled the emissions from gas given the same ΔQ, with electricity contributing a somewhat larger share than central heating (coefficient 0.430 > 0.403). This indicated that a decrease in demand for electricity and heat supply created a greater effect in reducing CO_2 per unit of saved energy than an equivalent reduction in gas consumption. Hence, priorities for energy efficiency measures should consider both the function of the building (which determines ΔQ) and the relative emission intensity by energy type when making decisions regarding the reduction of short- and long-term environmental consequences. To illustrate the aggregation of individual deviations at the group level of buildings, a pilot calculation was performed for a representative set of three types of objects listed in Table 2. Assuming equal weight for each case, the total deviation was: for natural gas – 3,754.28 kg CO_2/year, for centralised heat supply – 7,527.24 kg CO_2/year, for electricity supply – 8,108.94 kg CO_2/year. The average deviation per object within this sample was 1,251.43, 2,509.08, and 2,702.98 kg CO_2/year, respectively. The obtained values confirm that even on a small group of typical buildings, methodological discrepancies form a noticeable cumulative effect, which grows as the number of objects increases. In broader application for a block, district, or city, the aggregated effect should be calculated taking into account the number of buildings in each typological stratum, their area, operating modes, and the share of connection to a specific energy source. Within the scope of this article, such data were not available, so the presented calculation has a demonstrative nature and shows the principle of transition from an individual case to the group level.

Such a general expression serves as a basis for formalising different scenarios: a baseline scenario that fixes the existing calculation practice and modernisation rates; a scenario of gradual methodology harmonisation with a time profile of correction factors; a technological transformation scenario in which emission factors $EF_i(t)$ change as a result of power system decarbonisation or the widespread adoption of low-carbon technologies. The discrepancies obtained in the work between the DSTU and ISO/EN results have not an accidental, but a systemic nature: for a typical apartment, the annual energy demand differs by 35.3%, which in conversion to natural gas corresponds to roughly 901 kg CO_2/year; for an office and an educational classroom, the absolute deviation is even greater. In the article, the results are presented as a deterministic scenario comparison without confidence intervals and statistical characteristics of variability, so it is appropriate to interpret them as an estimate of methodological bias, and not as a probabilistic forecast. This type of gap between the calculated and actual or alternatively calculated energy consumption is well known in international literature regarding the performance gap and the sensitivity of models to input data and the level of detail.

The most important conclusion of the work is that the time scale of the model itself is the source of the systematic difference. This aligns with the study by H. Zhang *et al.* (2024) who showed that the results of a global sensitivity analysis for annual, monthly, and daily building energy consumption differ substantially, and finer time steps require more complex computations and provide a different picture of parameter influence. L. Zhu *et al.* (2022) demonstrated the feasibility of the Monte Carlo approach in combination with building simulation and global sensitivity for forecasting loads at the planning stage. A similar focus on the role of temporal discretisation and behavioural scenarios is also found in the scientific work of S. Norouziasl *et al.* (2024), where occupancy density and simulation step size significantly influenced the energy consumption of an office building. E. Kang *et al.* (2024) additionally showed that occupancy schedules and physiological characteristics of users can change office energy consumption even

within a single scenario. Therefore, the thesis regarding the key role of the time model is quite well-founded, but in this work, it is currently confirmed only by comparing two regulatory approaches, and not by current modelling. During the preparation of the study, V. Chupa *et al.* (2024) encountered the problem of selecting a methodology that would allow objectively comparing fundamentally different objects: certified biofuel (pellets) and morphologically heterogeneous municipal solid waste (MSW). In parallel, I. Vashchyshak *et al.* (2025) developed an improved methodology for energy auditing of underground heating networks, which ensures a more accurate identification of energy losses during transport.

For the practice of thermal modernisation, the conclusions of the current work also align with papers dedicated to renovation risk and the choice of measures. C. Carpino *et al.* (2022) showed that uncertainty and sensitivity analysis can reduce investment risk when applying energy performance contracts in the renovation of residential neighbourhoods. Also, Y. Deng *et al.* (2023) applied Morris's analysis to 14 enclosure parameters of an old residential district in Beijing and used it to select priority solutions considering climate change. M. Nasouri & N. Delgarm (2025) proposed a more formalised SBSA approach combining point and global sensitivity with Sobol metrics for a residential building in Iran, thereby showing a way to shift from descriptive comparison to quantitative ranking of factors. All these works confirm the validity of the idea that the calculation method influences reconstruction priorities and managerial decisions; however, they analyse uncertainty within a single modelling framework, whereas this study compares two different regulatory logic for energy efficiency calculations.

Publications on calibration and the performance gap additionally reinforce that part of the conclusions concerning the limits of permissible simplification. G. Chiesa *et al.* (2025) proved that weather data, occupancy profiles, internal heat gains, and ventilation can change the magnitude of the performance gap by up to 50% and more; This value is close to the discrepancy obtained between the approaches, although the reason for its occurrence is different – the article is not about measurement error, but about the methodological divergence between the standards. F. Johari *et al.* (2022) concluded that simplified building energy models can maintain acceptable calibration accuracy for urban-scale analysis if the purpose matches the level of detail. Q. Xue *et al.* (2025) determined that an approximate Bayesian approach is capable of calibrating uncertainty parameters significantly more accurately for a nearly-zero energy building, provided a sufficient dataset is available. Collectively, this means that this article convincingly reveals a systematic bias between DSTU and ISO/EN, but for complete scientific thoroughness, it lacks a real component, or rather a narrower, purely deterministic formulation of methods. Overall, this opinion corresponds to modern international practice in building energy efficiency modelling.

Conclusions

Methodological discrepancies between quasi-steady-state (DSTU) and dynamic (ISO/EN) approaches lead to systematic and quantitatively significant differences in the determination of annual thermal energy demand for various building types. Practical examples demonstrate differences on the order of tens of percent, resulting in substantial deviations in CO_2 emission estimates. These findings show that methodological inconsistency at the individual building level may propagate errors to national scales, particularly when results are aggregated at the city or country level. The aggregation analysis presented in this study indicates that the cumulative effect of methodological differences depends on building stock typology, the distribution of technical characteristics, and the structure of energy supply. The formulation of the "mismatch zone" concept and the proposed pragmatic threshold T provide an operational basis for identifying classes of objects for which the application of simplified methodologies is inappropriate. This establishes a clear criterion for distinguishing cases where a quasi-steady-state approach is sufficient from those requiring hourly dynamic simulations.

Quantitative assessment combined with the conversion of energy results into environmental indicators, confirm that correct interpretation of the impact of methodological choice requires simultaneous consideration of uncertainties in energy demand and variability in emission factors. The proposed analytical framework forms a practical platform for the quantitative justification of decisions and for the verification of national building stock assessments. In light of the results obtained, priority practical actions include: formalising procedures for recalculating results between methodologies to ensure harmonised reporting; developing criteria for methodology selection based on building typology and the mismatch zone concept; and creating representative statistical databases (stratified by building type and technical condition) to calibrate prior parameter distributions for simulations. Further research prospects concern several directions. An initial priority is to extend the analysis to a broader sample of real buildings with diverse climatic and technical characteristics, enabling refinement of mismatch zone topology and the development of regionally adapted methodological application rules. Furthermore, the approaches considered should be integrated with life-cycle assessment and energy system decarbonisation scenarios to link methodological discrepancies with long-term changes in emission factors.

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Коротко- та довгострокові екологічні наслідки методологічних розбіжностей у розрахунках енергоефективності будівель

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Анотація. В умовах глобальної декарбонізації точність оцінювання енергоефективності будівель стала критично важливим чинником прогнозування екологічних наслідків та досягнення ключових кліматичних цілей. Наявні розбіжності між національними та міжнародними методологіями розрахунку створюють суттєві ризики під час планування масштабних стратегій термомодернізації. Метою статті було кількісне оцінювання екологічних наслідків методологічних розбіжностей між квазістаціонарним та погодинним динамічним підходами до розрахунку енергоспоживання будівель. Розроблено комплексний підхід, що включає ієрархічне моделювання та детальну методику перетворення показників енергоспоживання в масу викидів вуглецю з ґрунтовним оцінюванням результатів. Встановлено, що основними джерелами методологічних розбіжностей є вибір часової моделі, формат подання кліматичних даних, опис теплової інерції та алгоритм інтерпретації внутрішніх тепловиділень. Доведено, що різниця в річній потребі в енергії при зміні методики розрахунку сягає кількох десятків відсотків. Це еквівалентно відхиленням маси викидів діоксиду вуглецю в межах сотень кілограмів. Для розв'язання цієї проблеми запропоновано концепцію «зони розбіжності», яка вводить порогове значення T для визначення доцільності використання спрощених методик залежно від необхідної точності. Обґрунтовано методику агрегування індивідуальних відхилень до рівня фонду будівель на основі детермінованого порівняння репрезентативних сценаріїв. Запропоновані математичні залежності для кількісного оцінювання підвищують надійність екологічного моніторингу, даючи змогу розробляти більш точні нормативні вимоги та зменшувати вуглецевий слід будівельного сектору

Ключові слова: декарбонізація; термомодернізація; вуглецевий слід; паливно-енергетичні ресурси; нормативно-правова база; динамічне моделювання