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Assessing the relationship between smart readiness and energy performance in Italian residential buildings

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Abstract. The Smart Readiness Indicator (SRI) provides a standardized framework for assessing the capability of buildings to integrate digital and automated functions that enhance energy efficiency, occupant comfort, and interaction with energy grids. Although the SRI scheme primarily focuses on non-residential buildings, its application can also be valuable in the residential sector, where the adoption of smart technologies and automation systems remains heterogeneous and often limited. Under the recent recast of the Energy Performance of Buildings Directive (EPBD IV), understanding the SRI's relationship with established performance metrics is increasingly important. This study aims to examine the quantitative relationship between the SRI and the energy performance of a sample of residential buildings in Italy. To this end, a statistical analysis is conducted to explore potential correlations between the SRI, along with its sub-scores (i.e., impact, domain, and aggregated scores), energy performance indicators (e.g., energy performance certificate and/or energy consumption), and building characteristics. The findings provide valuable insights for practitioners, designers, and policymakers involved in EU energy transition.

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1 Introduction

The recast Energy Performance of Buildings Directive (EPBD IV) reinforces the dual need to improve building energy efficiency and accelerate the digitalisation of building systems. Buildings in Europe account for about 40% of total energy consumption and 36% of greenhouse-gas emissions [1]. In this context, smart technologies are increasingly considered enabling solutions to enhance energy performance, operational flexibility, and indoor comfort [2].

In 2018 the 3rd EPBD introduced the Smart Readiness Indicator (SRI) as a framework to assess a building's capability to deploy Information and Communication Technologies (ICT) to improve energy efficiency, respond to occupants' needs, and interact with energy networks. Its recent recast (EPBD IV) further strengthened the role of smart readiness for large non-residential buildings. The SRI targets three core functionalities: (i) optimisation of energy efficiency and overall, in-use performance, (ii) adaptation to occupants' needs, and (iii) responsiveness to grid signals, including energy flexibility (European Commission, 2025). The assessment framework includes 54 smart services organised into nine technical domains and evaluated against seven impact criteria [3,4]. Services are scored across increasing functionality levels, reflecting progressive automation and control capabilities. Assessments can be performed through a simplified procedure for small buildings (Method A), a detailed expert-based evaluation (Method B), or a prospective automated approach based on BACS data (Method C). The final SRI score is obtained through service selection, functionality attribution, impact scoring with weighting, and aggregation. National authorities may adapt service catalogues and weighting schemes to account for local building stocks and climatic conditions. In parallel, Energy Performance Certificates (EPCs), while being the most established tool for assessing building energy performance in Europe provide limited information both on operational performance and building smartness, especially in relation to monitoring, control, and interoperability. EPBD IV, therefore, introduces major updates to EPC methodologies and explicitly highlights the complementarity between EPC and SRI, pointing towards a broader and more integrated evaluation of energy and smart performance across the European building stock.

Recent literature emphasises the need to integrate smart readiness assessment with established energy performance indicators, including EPC metrics and measured energy consumption [5]. However, evidence, especially for residential buildings, suggests that improvements in energy efficiency do not necessarily translate into higher SRI scores. For instance, studies on highly efficient residential buildings report no significant correlation between smart readiness and EPC class, indicating that smartness and energy performance capture distinct dimensions [6]. Similar conclusions emerge from analyses of high-performance standards (e.g., passivhaus), where high efficiency does not systematically imply high smart readiness [7]. Cross-country retrofit studies likewise show that SRI may increase without establishing a consistent quantitative dependency on EPC-based performance [8].

In this context, this study presents an exploratory statistical analysis of the SRI applied to Italian residential buildings, with the aim of investigating its relationship with energy performance indicators and building characteristics. The analysis focuses on the overall

SRI and its sub-scores and examines their correlations with EPCs and total energy consumption. The study is based on a dataset consisting of 22 residential buildings, including different building typologies (i.e., single-family – SFHs and multi-family houses – MFHs) and building conditions (i.e., existing, new and renovated).

2 Materials and Methods

Literature research was conducted across major scientific databases, leading to the selection of 2 peer-reviewed studies and 3 project reports based on specific inclusion criteria (English language, peer-review, methodological soundness, focus on residential buildings, presence of real case studies). These sources provided 21 existing case studies, complemented with 1 additional case evaluated by the authors within the Italian national SRI testing phase, resulting in a dataset of 22 cases. For each case, SRI scores and, when available, building characteristics and energy performance data (EPC and/or primary energy consumption) were collected. Statistical analyses were conducted in R, comprising tests for normality and homogeneity, one-way and robust ANOVA, non-parametric tests, post-hoc comparisons, and effect-size calculations, computed only when statistically meaningful, considering sample size and test applicability [9,10].

3 Results and Discussion

3.1 Case studies description

The dataset includes both SFHs and MFHs. In addition, for 15 out of the 22 selected buildings, the building condition (i.e., existing, new or renovated) was explicitly reported. Within this subset, 10 were existing buildings, 4 were new constructions and 1 was renovated building.

Table 1 summarizes the descriptive statistics of the analysed building sample, including the number of available observations, mean values, standard deviations, and minimum–maximum ranges for each variable. The dataset comprises 16 buildings with a building age of 1987 ± 21.5 (range 1955–2021). Where available, the year of major renovation was used instead of the original construction year to reduce potential bias related to building upgrades and retrofitting interventions.

Useful floor area data are available for only two buildings while EPC class are reported for 10 buildings, with an average value of 3.5 ± 2.1 on the A=1 to G=7 scale and the full range of EPC classes represented. Specific energy consumption is reported for seven cases, with a mean of 113 ± 62 kWh/m²·year and a wide range (33–215 kWh/m²·year).

The SRI of 22 buildings varied from 0% to 51% with an average value of 18 ± 14%. Among the SRI impact scores, the highest mean values are observed for Comfort (35%), while Energy Flexibility and Storage (9%) exhibits the lowest averages.

Among the domain scores, Heating achieved the highest score (32%), while and Monitoring and Control the lowest (5%). Electric Vehicle Charging was absent in all cases (0%).

Table 1. Descriptive statistics of the residential Italian dataset.

Building data	N	Avg	Std. Dev.	Min	Max
Building age	16	1987	21.5	1955	2021
Floor area (m2)	2	2160	1895	820	3500
EPC class	10	3.5	2.1	1	7
Energy consumption [kWh/m2 year]	7	113	62	33	215
SRI value (%)	22	18	14	0	51
Impact scores (%)					
Energy Efficiency (EE)	14	34	22	0	62
Energy Flexibility and Storage (EFS)	14	9	14	0	36
Comfort (COMF)	14	35	25	0	78
Convenience (CONV)	14	16	14	0	47
Health and well-being, and accessibility (HWA)	14	16	26	0	82
Maintenance and fault prediction (MFP)	14	11	15	0	39
Information to Occupants (IO)	14	11	17	0	67
Domain scores (%)					
Heating (H)	14	32	21	0	64
Domestic hot water (DHW)	14	15	25	0	61
Cooling (C)	10	29	21	0	52
Ventilation (V)	6	20	26	0	64
Lighting (L)	13	18	38	0	100
Dynamic building envelope (DE)	6	16	12	0	33
Electricity (E)	7	15	11	0	36
Electric vehicle charging (EVC)	3	0	0	0	0
Monitoring and control (MC)	14	5	14	0	53
Aggregated scores (%)					
1 - building	3	44	7	36	49
2 - user	3	42	13	27	50
3 - grid	3	18	11	10	31

3.2 Smart readiness of the investigated buildings

Fig. 1 to **Fig. 3** show the boxplots of SRI values and its sub-scores (namely, impact scores, and domain scores) for different building types (SFHs, MFHs) and condition (existing, new, renovated). No statistically significant differences are observed between SFHs and MFHs for the overall SRI (**Fig. 1**).
A comparable pattern is observed across all impact, domain, and aggregated scores. In all cases, distributions for SFHs and MFHs largely overlap, with similar central tendencies and wide internal variability.

In contrast, building condition significantly influences smart readiness. The overall SRI differs significantly among existing and new ($p < 0.01$). Existing buildings exhibit low SRI values (median = 15%), while new buildings show substantially higher values (median = 41%). The only one renovated building occupies an intermediate position (26%), though closer to new buildings than to existing ones. Post-hoc pairwise comparisons confirm statistically significant differences between existing and new buildings, whereas no significant difference is detected between new and renovated buildings.

All impact scores are significantly affected by building condition ($p < 0.01$). Existing buildings systematically show low median values, often close to zero, particularly for energy flexibility and grid services (FGS), maintenance and fault prediction (M&FP), and health and well-being (W&H), for which median values are equal to 0%. New buildings consistently present the highest median values across all impact categories, while the renovated building shows intermediate performance levels. For most impact scores, post-hoc analyses indicate significant differences between existing and new buildings (**Fig. 2**b).

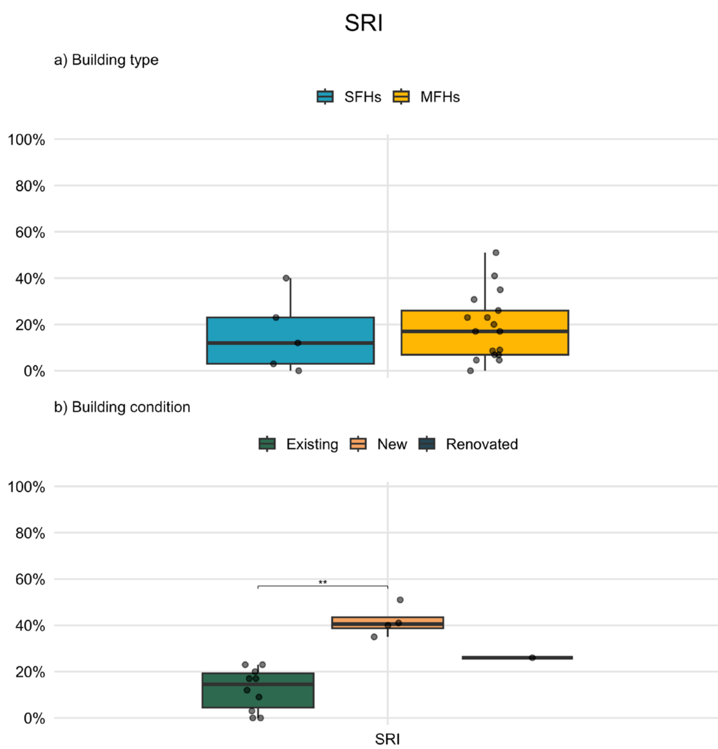

Fig. 1. Box-plots of the SRI between SFHs and MFHs and existing, new and renovated buildings.

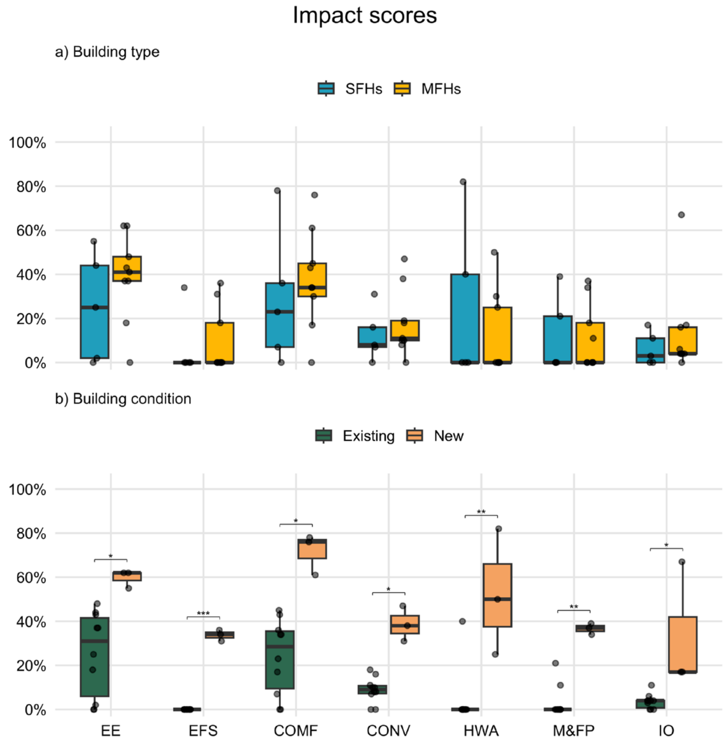

Fig. 2. Box-plots of the impact scores between SFHs and MFHs and existing, new and renovated buildings.

At the domain level, significant differences across building conditions are observed for most technical domains, including Heating (H), Domestic Hot Water (DHW), Cooling (C), Lighting (L), and Monitoring and Control (M&C) ($p < 0.05$). Existing buildings generally exhibit median values close to zero for these domains, whereas new buildings show substantially higher median scores.

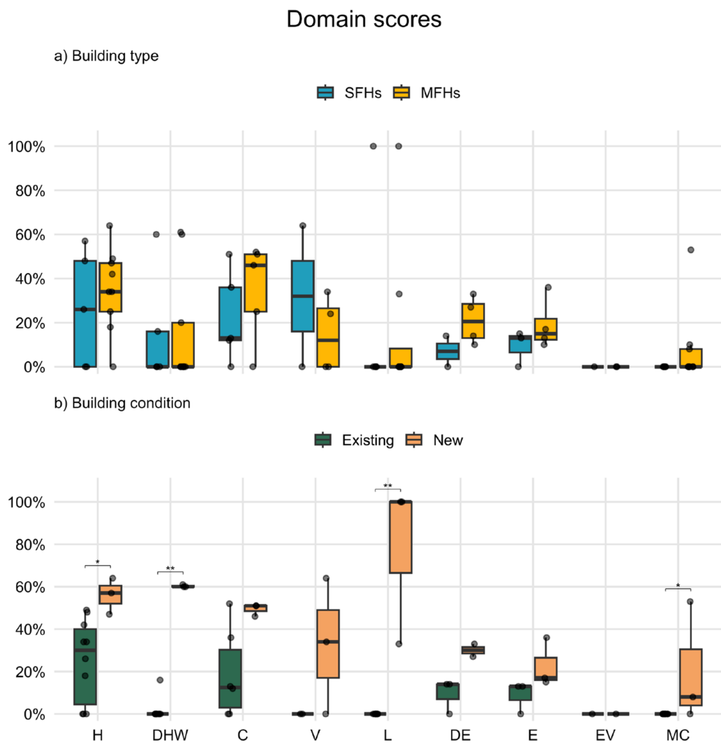

Fig. 3. Box-plots of the domain scores between SFHs and MFHs and existing, new and renovated buildings.

Fig. 4 illustrates the relationships between the SRI and two energy-related variables, namely EPC class and total primary energy consumption. The analysis reveals a statistically significant, moderately negative correlation between SRI and EPC class ($r = -0.683$, $p = 0.0295$, $R^2 = 0.466$, $N = 10$). The corresponding linear regression shows a negative slope (–9.67), with data points following an overall decreasing trend but displaying considerable dispersion. Overall, these results suggest the presence of a moderate association between SRI and EPC class; however, its magnitude remains limited, as the two indicators capture complementary rather than overlapping information.

Regarding total primary energy consumption, the correlation with SRI is also negative ($r = -0.513$), but weak and not statistically significant ($p = 0.239$, $R^2 = 0.263$, $N = 7$). Accordingly, the data exhibit substantial dispersion across the entire range. This outcome is likely influenced by the reduced sample size and, consistently with the literature, by the fact that actual energy use is strongly affected by external factors (e.g., occupant behaviour and operational practices) that are not captured, or only partially captured, by SRI/EPC certification frameworks.

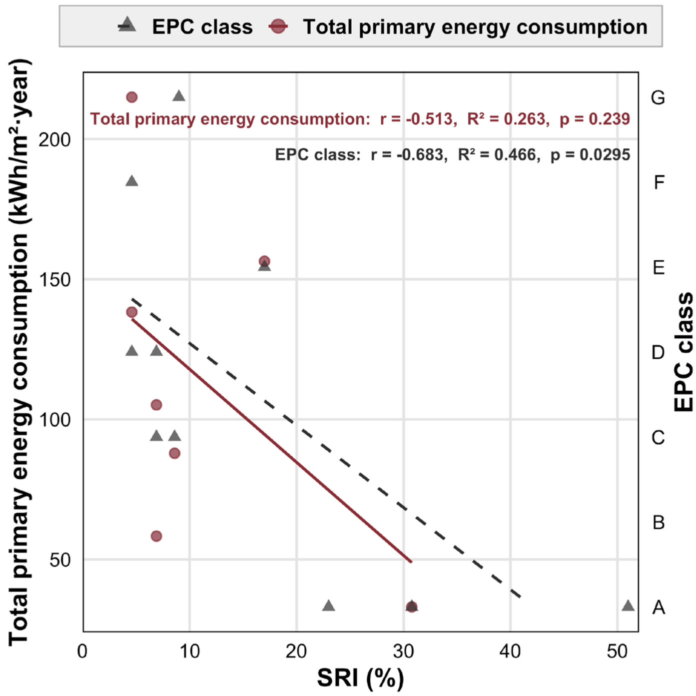

Fig. 4. Relationship between SRI and energy performance indicators for the Italian sample. The figure shows the correlation between SRI and EPC class (triangles, dashed regression line) and between SRI and total primary energy consumption (circles, solid regression line). Linear regression lines, Pearson correlation coefficients (r), coefficients of determination (R^2), and p-values are reported in the plot.

4 Conclusions

This study investigated the relationship between the Smart Readiness Indicator (SRI), energy performance indicators, and building characteristics in a sample of residential buildings, with a specific focus on the Italian context. Using a dataset of 22 Italian buildings, the analysis explores a statistical assessment of SRI across different building types and conditions.
The results confirm that residential buildings exhibit generally low levels of smart readiness, particularly with respect to energy flexibility, monitoring and control, and grid interaction services. No statistically significant differences are observed between single-family and multi-family houses. In contrast, building condition plays a significant role: new buildings consistently show higher SRI values and sub-scores compared to existing buildings. Correlation analyses indicate a moderate and statistically significant relationship between SRI and EPC class, whereas no significant relationship is found between SRI and total primary energy consumption. These results highlight the partial alignment between smart readiness and EPCs, while also confirming that smart readiness and energy consumption capture distinct aspects of building performance. Overall, the

findings support the view that the SRI provides complementary information to traditional energy performance metrics and can contribute to a more comprehensive assessment framework under the EPBD IV. However, the limited sample size and uneven data availability underline the need for larger, more harmonised datasets to further investigate the quantitative relationships between smartness, energy efficiency, and operational performance in the residential building stock.

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