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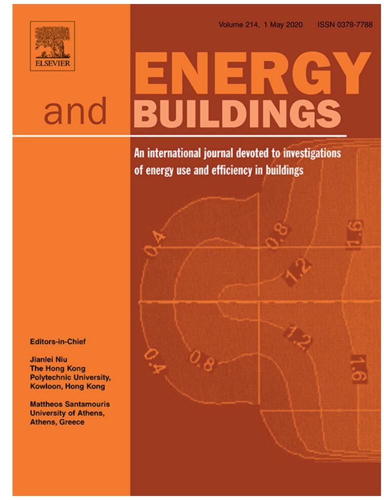

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A new method for estimating the smart readiness of ~~large numbers of buildings~~building stock data using Display Energy Certificate data

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Abstract

The Smart Readiness Indicator (SRI) was introduced by the revised Energy Performance of Buildings Directive (EPBD) 2018/844/EU, as a voluntary scheme for rating the smart readiness of buildings. The methodology addresses the benefits of smart technologies and their functionalities in buildings to offer low-energy, healthier, and environmentally comfortable buildings that balance the needs of occupants and the energy grid. This is a case study implementation of the SRI calculation to the university campus scale. The SRI methodology is applicable on a building-by-building basis; however, the assessment of large stocks and energy hubs is not addressed and will be the focus of this study. Other studies have proposed a method to extend the calculation to building clusters which, however, involves assessing all the buildings in the cluster in detail. The current case study extends to a much larger number of buildings ~~and~~, therefore, the assessment of each individual building was not considered effective. A critical implementation of the SRI calculation is presented here that ~~considers~~leverages publicly available information like Display Energy Certificate (DEC) advisory recommendation reports for a university campus. A complex building is used to verify the proposed method based on the SRI detailed methodology. ~~This~~The proposed method provides a solution to the large-scale processing of building information across multiple complex buildings, hence benefiting decision-makers early on. Furthermore, the method benefits from the inclusion of building-specific recommendations based on DEC surveys. For the 98 buildings examined, a campus SRI score range has been estimated and focus areas have been identified as the foundation of smart energy and net-zero transition pathways.

Keywords: EPBD, Smart Readiness Indicator, Display Energy Certificate, automated SRI calculation, university campuses

Abbreviations

Abbreviations	
AHU	Air-handling unit
AI	Artificial Intelligence
AR	Advisory Report ~~(DEC)~~
BACS	Building Automation and Control Systems
CCC	Climate Change Committee
CHP	Combined Heat and Power
DEC	

DHW	Display Energy Certificate
DSM	Domestic Hot Water
EC	Demand-side Management
EPBD	European Commission
EU	Energy Performance of Buildings Directive
HVAC	European Union
HE	Heating Ventilation Air Conditioning
ICT	Higher Education
IoT	Information and Communication Technologies
IPCC	Internet of Things
ML	Intergovernmental Panel on Climate Change
NZEB	Machine Learning
SRI	Nearly Zero Energy Buildings
TABS	Smart Readiness Indicator
TBS	Thermally Activated Building Systems
VBA	Technical Building Systems
	Visual Basic for Applications

1. Introduction

Climate adaptation and resilience ~~is tightly~~are intrinsically connected to the adaptation of the urban environment, as rapid urbanisation is both a key concern and an opportunity to tackle climate change [1]. Globally, compliance with the Paris Agreement's 1.5°C limiting global warming target has spurred a race to net-zero emissions by 2050 with the United Nations urging governments to strengthen their action plans through strict National Determined Contributions (NDC) [2]. ~~S~~ Significant advances in international policy now provide route maps to net-zero transitions, with the energy sector being a major focus. Buildings are large energy consumers, and the growing energy demand predictions ~~are calling~~call for unprecedented technological, planning and social changes [1]. In the UK, compliance with the CCC's binding Sixth Carbon Budget requires building carbon emissions to be eliminated by 2050 [3]. Europe has committed to making all new buildings nearly zero-energy (NZEB) starting ~~from~~in 2020 and progressing towards zero-emission buildings by 2030. A comprehensive revision of the 2018 Energy Performance of Buildings Directive (EPBD) and the European Green Deal [4] ~~aim~~aims to achieve a fully ~~decarbonized~~decarbonised building stock by 2050, positioning Europe as the first climate-neutral continent [5]. ~~The directive also,~~ For the first time in EU legislation, the directive also recognises the importance of building intelligence in driving down energy demands, enhancing building environments and the role that buildings can play in a flexible, decarbonised energy system that shifts from being infrastructure-lead to service-lead [6].

A key implementation mechanism of the EPBD directive is the "Renovation Wave" strategy ~~that was~~ presented in 2020~~,~~ as part of the European Green Deal that aims to double the energy renovation rate of buildings by 2030 and encourage wider deep retrofits [7]. Consolidation of some key measures was considered necessary to achieve this rate. These include the digitalisation of the ~~Energy Performance Certificates~~building energy performance certification (EPC), the introduction of building renovation passports and building system modernisation that better integrates energy systems to the building level (domains include heating, cooling, ventilation, charging of electric vehicles and renewable energy). The latter has been the focus of the "Smart Readiness Indicator" (SRI~~), an~~). This instrument ~~that~~ was introduced by the EPBD to address the gap in the assessment and certification of smart building technical systems [8]. ~~The scheme,~~ As explained further below, the scheme provides an assessment methodology and certification. On a building-by-building basis, it rates a building's potential to integrate smartness under nine domains like EPCs and Display Energy Certificates (DEC~~) demonstrate~~), demonstrating a building's energy efficiency rating.

Increasingly, energy transition pathways highlight the role that sub-national actors like cities, communities, public-private entities etc~~.~~., play in addressing climate change [9]. The necessity for a whole systems and cross-sector response to the climate crisis has also been highlighted in various net-zero transition roadmaps and frameworks [10–12]. At district scale, university campuses typically represent large building portfolios, are large energy consumers [13] and pose significant potential for decarbonisation [14]. Drawing from previous research [15], this paper emphasises buildings and campuses as active participants in the energy system, exploring the integration of smart technologies to tap into their carbon mitigation potential. In lieu of an established smart energy campus-specific assessment, this research applies the SRI assessment to the building stock of a reference university campus to assess the extent to which publicly available building data can provide the basis for stock-level assessment. The SRI, covering various energy vectors like heating, power~~,~~ and electric vehicles, was considered an appropriate starting point for university campus smart energy assessments. Additionally, the use of publicly available data for the assessment is examined as an alternative to the traditional resource-intensive building survey-based SRI assessment~~, aiming~~. The aim is to overcome this resource barrier and also link the SRI assessment to established building energy efficiency schemes like EPCs and DECs.

1.1. Smart Readiness Index (SRI) and Display Energy Certificates (DEC)

The governing frameworks that the EU has brought forward to drive national energy efficiency regulation and standards are in the form of three directives~~,~~: The Energy Efficiency Directive [16], the Energy Performance of Buildings Directive (EPBD) [17] and the Renewable Energy Directive [18]. Having come into play in 2002 and with two updates in 2010 and 2018, the EPBD is increasingly tightening the energy efficiency requirements for buildings in the EU. The last amendment, EPBD 2018/844/ EU, introduced the smart readiness indicator (SRI) and the need for a common EU rating scheme for three key building functionalities: adaptation to occupant needs~~;~~, adaptation to external grid signals and optimisation of in-use building operation to increase energy efficiency and overall performance. It also mandates the development of a common definition and assessment methodology to guide national implementation. As a result, a consortium research study was commissioned by the European Commission (EC) that produced the current calculation framework detailed in a report published in 2020 [19] and ~~co-ordinated~~coordinated the methodology's non-committal testing and validation phase ~~of the methodology~~. Initial testing revealed, albeit on a limited number of buildings, a premise of 'low total SRI score' and a large opportunity for smart-readiness improvement in areas such as dynamic envelopes~~,~~ and flexibility and storage capabilities [20].

As a spreadsheet tool, the calculation framework~~, in the form of a spreadsheet tool,~~ organises qualitative indicators in a matrix of technical domains, technical services related to each domain, and impact criteria (see Table 1).

The SRI assessment allows buildings to be evaluated using one of three possible methodologies. In its simplest version, Method A, the calculation follows a ~~check-list~~checklist approach that allows self-assessment but not for certification purposes. It ~~is~~ also focuses on a subset of the smart-ready services ~~as opposed to~~instead of the full list that the detailed assessment Method B considers. Method B requires on-site inspection, and certification is possible when a trained expert ~~is carrying~~carries out the assessment. Method C~~, finally,~~ allows the assessor to select only the smart-ready services relevant to the assessed building ~~being assessed.~~. Overall, the methodology applies different weighting factors, for climate zone and building type, to each of the domains and impact criteria that, if needed, can be customised by the user based on the assessment specifics. Although the SRI is a relatively new topic, various studies have highlighted that the SRI process can be resource-intensive~~, is~~ and restricted to a building-by-building assessment approach [21,22]~~, with~~. Most studies are limited to specific case study buildings [23–25], but they nonetheless report on methodological gaps that the SRI needs to address for different contexts and climates [26,27]. This study [28] which focused on specific regional building contexts like Mediterranean non-residential buildings, found that SRI scores were not reflective of the buildings' energy performance needing weighting factor adjustment. Additionally, energy retrofit was found less effective in improving the SRI score based on two case study buildings. The subjective score assessment by the assessor and ~~a~~the difficulty ~~to draw~~in drawing comparisons between different buildings with different services present ~~[23].~~ were also highlighted [29]. District-level studies are limited in number; one of them suggests the extension of the EPC framework to quantify the load-shifting potential of districts [30] with theoretical application scenarios presented here [31]. Canale et. al [32] propose the categorisation of residential building stocks under typologies to estimate building stock-wide SRI levels in Italy. A lack of studies was therefore found addressing the detailed calculation of the SRI based on specific building data at scale and will be the focus of this study.

The EU Commission recognises the SRI additionalities with the EPC scheme (and subsequently DEC) in the efforts to enhance building energy performance and occupant awareness on energy efficiency. Furthermore, the SRI guidance qualifies EPC assessors for issuing SRI certificates. In that light, this research seeks to examine potential links and the integration of the more established EPC/DEC schemes with the SRI scheme. Particularly relevant to university campuses, the DEC scheme has been in place since 2008 and monitors the measured energy performance of large public non-domestic buildings in England and Wales ~~[24]~~[33]. DECs present the annual energy use and associated carbon emissions of a building, alongside a normalised A-G grade that represents its performance relative to benchmarks produced for similar buildings. For buildings that require DECs, an accompanying Advisory Report (AR) must also be produced every 7-10 years ~~[24]~~[33]. The ARs contain building improvement recommendations with accompanying estimates of the likely economic and environmental impacts (e.g., "Consider installing building-mounted solar water heating" with a predicted 'long' payback period and 'medium' impact on building emissions). These recommendations, produced by DEC software in conjunction with the knowledge and expertise of the building's assessor, therefore provide further detail on a building's characteristics and its improvement potential.

A public DEC database has been available for several years ~~[25]~~[34]. While this does not include all the variables collected in the DEC process, it does cover building performance, including annualised electricity and fossil-thermal energy consumption, alongside key building characteristics such as total floor area, main internal environment (e.g. air-conditioned or naturally ventilated), and main heating fuel. Additionally, the recommendations and associated predicted impacts from the ARs are also included. As a source of large-scale, disaggregated, and long-term empirical data, DECs have been used to research the non-domestic stock in numerous studies over the years. This includes statistical analyses of building performance ~~[26–28]~~[35–37], as well as studies that use the DEC data as inputs for building simulation ~~[29]~~[38].

1.2. Smart energy integration and decarbonisation of university campuses

Considering the wider energy system, the SRI aims to align with the EU's action plan for the digitalisation of energy, 'Digitalising the energy system - EU action plan' ~~[30]~~[39]. Smart-ready buildings are thought to play a key role in facilitating the integration of renewable energy in decentralised, flexible energy systems ~~[31]~~[40]. A smart-ready building, with the use of automation and smart technologies, is expected to be healthier, more comfortable, low-energy and flexible. Flexibility enables smart-ready buildings to operate as active nodes in a smart energy system ~~[32]~~[41]. A systematic literature review demonstrated how university campuses have integrated various smart energy vectors in their operations, like smart energy monitoring and renewable generation monitoring, to optimise their energy usage ~~[33]~~[15]. Using Internet of Things (IoT) technologies, Artificial Intelligence (AI) and Machine Learning (ML) they can proactively manage energy usage, allowing for demand-side response management. Other universities utilised dynamic energy pricing, adding flexibility to the power grid by exploring load-shifting opportunities or even decoupling from the central grid and operating in self-sufficient mode (Ibid.). Information and Communication Technologies (ICT) are also used for smart learning and governance as well as monitoring internal environmental conditions and adapting to occupant needs (Ibid.).

At a district- or campus -scale, clustering of buildings can increase the opportunities for energy sharing and load shifting ~~[34]~~[30], although these are not currently considered in the SRI. Additionally, while the SRI offers an assessment of the readiness of buildings to participate in flexibility schemes, it does not provide any basis for quantifying the flexibility potential. The importance of clustering and scale has been recognised by the International Energy Agency (IEA) Annex 67 ~~that~~which also highlights the importance of user comfort and acceptance of any flexibility strategies ~~[35]~~[42].

Research highlights that currently, building energy performance certification (EPC) lacks harmonisation with smartness and excludes any smart building and smart city elements ~~[36]~~[43]. Instead, it suggests a methodology to extract Building Automation and Control Systems (BACS) information and SRI input from BIM models and integrate both to a next-generation EPC scheme~~[36]~~ [43]. Another study ~~[37]~~[44] suggests reorganising EPCs under eight assessment themes, including the SRI, comfort, outdoor air pollution, real energy consumption, district energy and enhanced communications, to create a hybrid assessment method. The potential interactions of the two schemes have also been recognised elsewhere, highlighting that learnings from the EPC scheme can be taken forward to the SRI, but also arguing that the SRI can contribute to closing the performance gap and benefitting building energy performance certification by further facilitating energy renovations ~~[37–39]~~[44–46].

1.3. Research goals

Considering the ~~above~~ need to catalyse building energy renovation and the transition to a decarbonised energy system, the research aims to identify connections between smart readiness and common building energy certification schemes i.e., using publicly available building information to assess smart readiness at building stock level. With a specific focus on university campuses, it is believed that this methodology can provide a blueprint for rapidly drawing insights for the technical domains of a large number of buildings, without undertaking detailed surveys~~.~~ as part of the initial screening. This approach could benefit organisations in the early stages of planning their transition to district level decarbonisation.

Contributions:

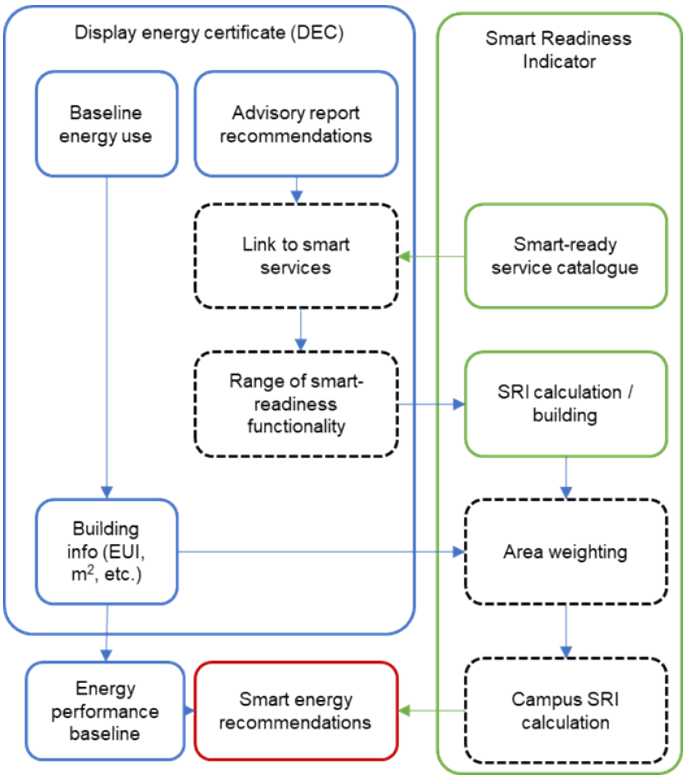
- ~~Propose a~~A novel method to automatically use DEC advisory report recommendations to assess the SRI services for each building within a campus stock and calculate an area-weighted whole-campus Smart Readiness Indicator.
- ~~Propose a method of~~The approach's novelty also lies in scoping potential smart integration interventions for university campuses based on their current degrees of smart readiness and the areas lacking in smart -readiness.

2. Methodology

Considering the limitations of the SRI methodology ~~as previously mentioned~~that requires extensive data collection and onsite inspection undertaken per building, this method proposes to utilise the DEC advisory reports to extract existing building information and evaluate campus smart readiness at a disaggregate (individual building) level. Utilising the DEC advisory report recommendations, this new methodology entails:

- collecting DEC data for each building ~~in~~on the campus,
- generating links between DEC advisory report recommendations and SRI services,
- calculating the SRI scores (for best and worst case) per building using the DEC data,
- producing an overall area-weighted SRI score for the whole campus.

Based on the steps above, Figure 1, illustrates how the SRI calculation is adapted to integrate DEC recommendations with the smart-ready service assessment. By linking smart-ready services to DEC recommendations, a range of scores can be automatically calculated for each building and an area-weighted score estimated for the whole campus. Post-processing the campus DEC recommendations and smart-ready services also provides insights into what measures can be implemented to improve the smart-readiness of the campus and an overview of campus operational energy performance based on DECs.



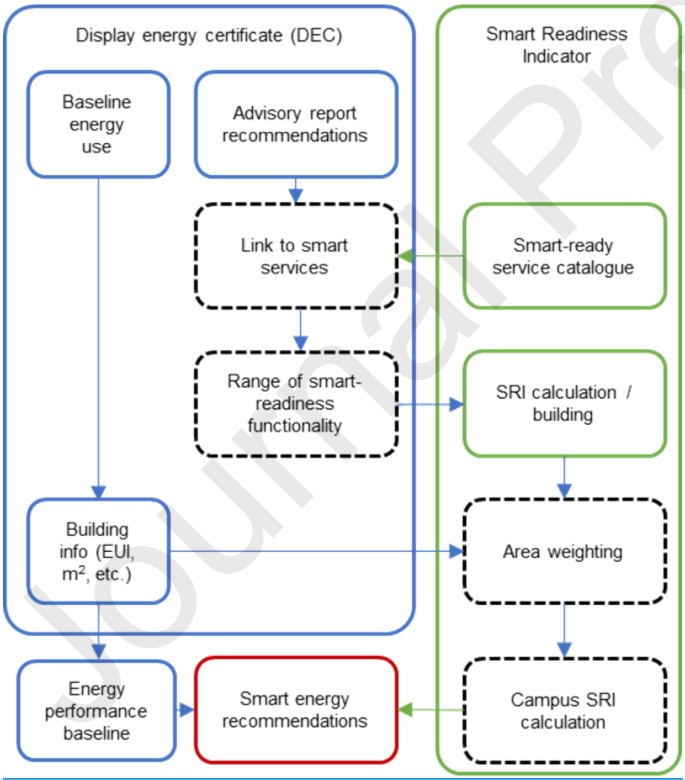


Figure 1: Method diagram for the assessment of campus-wide smart readiness using DEC advisory reports. Dotted outlines signify the proposed method modifications.

The assessment and rating scheme utilises a calculation spreadsheet [19], that at the time of writing is only available for testing purposes. Several smart-ready services are assessed and scored based on their functionality levels over nine smart domains and seven impact criteria. Overall, the detailed Method B, lists a total of 54 services, compared to 27 applicable to the simplified Method A. Method C, as explained previously, allows flexibility to the assessor to create a bespoke selection of relevant services. Weights are assigned to each service and impact score based on the climate zone and type of the building (i.e. residential or non-residential). The key principles and domains of the SRI framework are summarised in Table 1. For each of the smart services, a score of 0-4 is assigned based on the functionality level, with level 0 referring to a non-smart-ready service and the highest level signifying an advanced functionality for this service. The highest score achievable per smart service varies between 2-4. In the case of services or domains that may be irrelevant to the assessed building, they are discounted from the calculation following a triage process [19]. The overall SRI score is calculated as the weighted sum of all sub-scores per impact criterion ~~taking into account~~considering domain weightings. Specific domain scores are also calculated by applying impact weightings.

2.1. DEC data collection

For the present implementation study, DEC and AR data was collected for certificates lodged until late 2021. The complete database consists of 426,633 certificates, across all building uses and locations in ~~the UK.~~England and Wales. The SRI for university campuses was tested using a UK urban university campus.

The process of narrowing down to the desired university campus DECs was undertaken using 3DStock; a highly detailed, fully disaggregate building stock model which includes DEC and EPC data address-matched to each property ~~[40]~~[47]. A list of buildings within the university campus was matched to addresses within 3DStock, which were used to identify the associated DECs and ARs. DEC data was grouped based on the building and lodgement year, and for buildings with multiple years of lodged DECs and ARs, the most recent year was selected. Depending on the internal breakdown, a single building may require multiple DECs to be lodged (e.g. separate DECs for sections of the building associated with distinct occupiers or uses). These cases were identified using the 'Building Reference Number' within the DEC database.

Across the database, the majority of AR recommendations use a set of ~~standarised~~standardised 'recommendation codes' ~~[41]~~[48]. For example, ~~CON17~~'CON17' is to consider installing HVAC timer controls. Across all recommendations in the ~~entire~~ DEC database, 13.4% ~~of recommendations~~ are not provided with a recommendation code. Keywords were used to link these unclassified recommendations to specific recommendations within the DEC process where possible. Unclassified recommendations were listed and checked for overlapping content, followed by categorisation to the closest AR recommendation group (see Table 1). ~~Key words~~Keywords from the coded recommendations were extracted and ~~then~~ matched to the unclassified recommendations where possible. For 9% of the unclassified recommendations, this was not possible~~,~~ since they could not ~~clearly~~ be linked (e.g. "install water-saving devices").

Table 1 presents the full list of SRI smart domains available through the EPBD guidance [19]. In the SRI methodology, ~~assessment of the~~ smart-ready services ~~is made~~are assessed against the impact criteria presented in the same table. Similarly, the DEC recommendations are organised under different groups ~~too~~. The two methods overlap in most categories, except for the fabric recommendations that the DEC assessment includes, ~~and~~ the disaggregation of lifts and catering ~~as well as~~, ventilation systems, and heating systems. During the DEC data collection, 76 unique coded recommendations were identified, split under 13 coded categories.

Table 1: EPBD SRI domains [19] *and DEC advisory recommendation groups*

SRI Domains	Smart service impact criteria	DEC recommendation groups ~~[42]~~[49]
Heating **(H)**	Energy efficiency	Operation and management **(OM)**

SRI Domains	Smart service impact criteria	DEC recommendation groups ~~[42]~~[49]
Domestic hot water **(DHW)**	Maintenance & fault prediction	Fabric **(BF)**
Cooling **(C)**	Comfort	HVAC controls **(CON)**
Controlled ventilation **(CV)**	Convenience	Ventilation – Natural **(V)**
Lighting **(L)**	Health, well-being and accessibility	Ventilation – Mechanical **(V)**
Dynamic building envelope **(DE)**	Information to occupants	Ventilation – Mixed **(V)**
Electricity **(E)**	Energy flexibility and storage	Small power **(SP)**
Electric vehicle charging (**EV)**		Lighting
Monitoring and control **(MC)**		Cooling **(AC)**
		Lifts **(LE)**
		Catering **(CA)**
		Boilers **(HS)**
		Hot water **(HW)**
		Alternative energy **(AE)**
		Maintenance **(X)**

2.2. DEC to SRI links

The premise of the proposed method is that DEC recommendations and smart-ready services can be linked to draw an understanding of a buildings' and, subsequently campus's smart readiness (i.e. a ~~buildings~~building's DEC recommendations can be used as input data for its SRI calculation). ~~Where a building recommendation is linked to an SRI service in this way,~~ A corresponding potential range of smart functionality levels is ~~also~~ assigned when a building recommendation is linked to an SRI service in this way. When all the separate recommendations for a building are processed, they make up the list of smart-ready services and levels applicable per building. Where appropriate, DEC recommendations are linked to multiple SRI domains. DEC recommendations that could not be directly linked to a service were excluded. So, for example, a DEC recommendation to consider installing HVAC timer controls (CON17) has been linked to SRI domains H-1a (heat control, demand side), C-1a (cooling control, demand side) and V-1a & V-1c (ventilation, ~~air flow~~airflow control).

Following the single-building SRI methodology [19], this study assigns functionality levels to the smart-ready services based on the respective DEC recommendation. Considering the brevity of the DEC recommendations, ~~there is~~this approach introduces a level of uncertainty ~~introduced by this approach~~ to attributing functionality levels. To limit the uncertainty, ~~a~~ minimum and ~~a~~ maximum functionality ~~level~~levels have been produced for each of the recommendation and service matches. In the example above, the interpretation of the recommendation to install timer controls results in the following scores: H-1a(0-2), C-1a(1-2), V-1a (0-1) and V-1c(0-1) minimum and maximum levels respectively. This way, the possibility of zero HVAC time controls is represented by a zero smart functionality level for the service up to the maximum functionality implied by the recommendation (e.g. the minimum functionality level for H-1a is “No automatic control” and the maximum attributed level is “Individual room control (e.g. thermostatic valves, or electronic controller)”. Finally, where a building has multiple recommendations linked to individual services, the maximum attributed score was considered per service. So, if the example building had two recommendations that are linked to functionality levels of 0-2 and 0-3 for the H-1a service, then an overall range of 0-3 would be applied. Through this process, all possible links were made~~,~~. The scores can be nonetheless reviewed and adapted ~~by prospective assessors~~should the method be implemented centrally.

The processing of the DEC data, including the code to translate recommendations to SRI services and functionality levels was written in a PostgresSQL database. A full list of the links between DEC recommendations and SRI services, along with the corresponding minimum ~~&~~and maximum levels, is provided in APPENDIX A.

2.3. SRI calculation at building and campus level

~~Having linked the DEC recommendations to the SRI services,~~ The calculation for a specific set of buildings can be produced by linking the DEC recommendations to the SRI services. The calculation steps are outlined here and illustrated in Figure 2:

1) Initial triage process is completed for the campus by excluding whole domains where not applicable to the buildings as per the SRI methodology e.g., electric vehicle charging if it is known that none exists. When calculating the SRI for individual buildings, this can be done through a detailed survey, but under the present proposal, which aims to calculate SRI at scale, such an approach is not practical. Triage for the smart-ready services is, therefore, done automatically, based on the DEC matching process described previously. Where a link between a DEC recommendation to an SRI service exists, this service will be included in the calculation. Services not linked to a recommendation are excluded. This way, the calculation assesses the smart readiness of existing services as described in DECs so as not to ~~negatively~~ affect the assessment negatively [21]. The services not included in the calculation signify the areas for further improvement towards smart-ready buildings and considerations for expanding the DEC recommendations to include smart considerations.
2) Process the DEC recommendations for each building, using the method described in the previous section.
3) The SRI calculation is based on the latest calculation spreadsheet~~,~~ provided by EPBD for testing purposes ~~[43]~~[50]. Two overall SRI scores are calculated~~; once~~, each using the minimum and maximum functionality levels for each ~~of the services~~service from the DEC recommendations.
4) The building~~-~~ and campus-scale SRI calculations were implemented by adapting the existing SRI Excel files with VBA code to cycle through large numbers of buildings. The code iteratively goes through the SRI calculation per building and calculates the minimum and maximum score per building and per DEC AR~~.~~ (see equations (1), (2)). For this selection, the code calculates minimum and maximum total area-weighted SRI scores for the campus stock~~,~~ (see equation (3)), using the

floor area data for all buildings ineach assessed building and the assessment, using the following equations:total campus floor area.

$$Smart\ Readiness\ Indicator_{min} = \sum_{i}^{n} service\ score_{min} \text{x impact weight for domain} \quad (1)$$

$$Smart\ Readiness\ Indicator_{max} = \sum_{i}^{n} service\ score_{max} \text{x impact weight for domain} \quad (2)$$

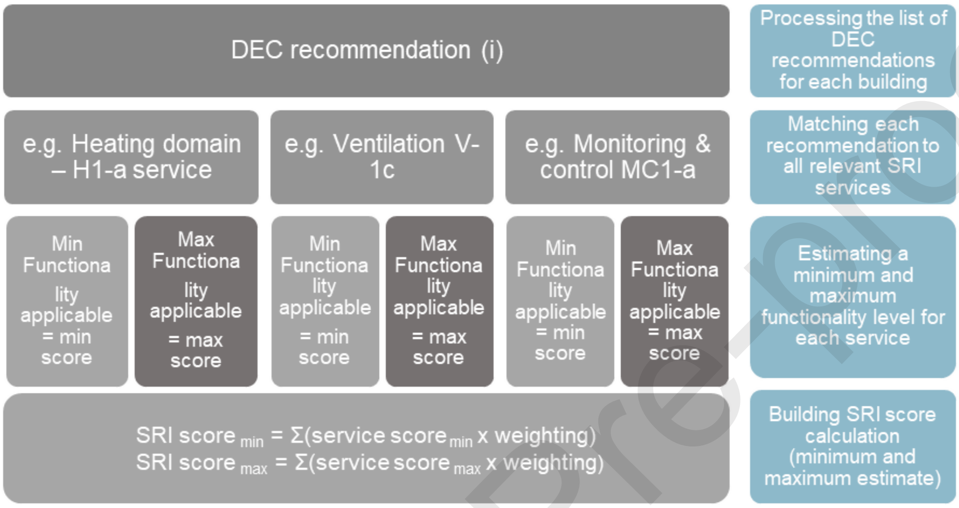


Figure 2: SRI calculation steps per building

$$Smart\ Readiness\ Indicator_{total} = \sum_{i}^{m} SRIi\ x\ (building\ area\ weighting)i \quad (3)$$

2.4. Case study

The case study implementation of the DEC-based SRI calculation was undertaken in two parts, described below:

- Building-scale: FirstlyFirst, a comparison between the standard SRI calculation and the proposed method for a single university building. The detailed Method B was used to includeincluded the full range of smart -services. The selection for the building was based on two main criteria,: availability of technical and operational information and sufficient complexity in terms of building systems to maximise the scope of the testing. A desktop assessment was undertaken for testing purposes, as there was sufficient information for all the assessment domains.
- Campus-scale: Secondly, a calculation of the overall campus score for the university buildings that havewith a DEC and using the methodology described in this study.

A summary of the campus and the building used in the case study is provided in the following subsections.

University campus summary

The studied university campus comprises 216 buildings spread around a large urban area. According to the studied DECs, more than a third of the studied buildings were built between 1945 and 1980, a third was built pre-1914, 20% of the buildings were classed as post-1980, and around 8 % of the buildings were built between 1919 and 1939. In terms of usage, around 27% of buildings are classed as labs with medical uses, residential and teaching buildings each occupy around 20% of the campus. Libraries occupy around 12% of buildings; the remaining buildings comprise administration buildings and chemical and engineering labs. Lastly, in terms of energy efficiency, about half of the studied buildings had a rating of C and above.

Out of the total 216 buildings, 98 were within the research scope, i.e~~.~~., large enough floor area to require a DEC. In the case of the studied campus, many buildings are Victorian terrace conversions under the size threshold of 250m^2. ~~In terms of~~Regarding ARs, the median number of recommendations found per building-and-lodgement year is 14, with ~~the~~an interquartile range of 11-15. A recommendation code was not provided for 6.7% of the campus's AR recommendations~~, a recommendation code was not provided~~.

Case study: key building characteristics

A Grade II listed university building was selected for assessment. It is a 5-storey, 4,599m^2 multi-use building ~~originally~~ built in the early 20th century as a science teaching and lab building. It has been recently partly refurbished to provide teaching, research laboratory and social spaces. Additionally, the building is shared by four different departments ~~that were~~ introduced at different stages ~~and that~~, which the refurbishment sought to consolidate. An overview of the building characteristics and the resulting triage exclusions is displayed in Table 2.

The results of the triage process indicate that the heating, cooling and domestic hot water domains are present, with multiple systems serving different parts of the building ~~(~~, e.g. low-temperature hot water (LTHW) from district heating and gas boilers, chillers and localised direct expansion (DX) heat pumps~~)~~.. Regarding the ventilation domain, all labs and ~~generally~~ most of the building ~~is~~are served by air-handling units with mechanical ventilation and heat recovery~~, however, there are~~. However, some office areas ~~with~~have natural ventilation and manual window opening. The dynamic envelope features are limited to manually operated roller blinds for solar shading and manual window opening, not connected to the mechanical ventilation plant. The labs within the building have been designed for close-control requirements that do not usually allow for ~~fluctuations in~~ temperature and humidity ~~in most cases.~~fluctuations. In terms of electricity, the building does not generate renewable energy or have electricity storage capacity. Relevant services ~~were therefore excluded as well as~~ and those associated with combined -heat and power (CHP~~), that~~) were excluded, which is also not present in the building. In terms of monitoring and reporting, the building is connected to a central building -management system that monitors the operation of the equipment in real -time. Reporting for end-uses is available through historical energy data. Finally, the building does not present any flexibility capacity and demand-side management control. Building information is organised based on the SRI calculation process and the available input options.

Table 2: Building information organised based on the SRI calculation process and the available input options.

Building information	**Triage process**		
	Domain	**Input information**	**Services excluded**
Building type: Non-residential	Heating	District heating (multiple systems present including gas boilers ~~and heat pumps~~)	H-1b: Emission control for Thermally Activated Building Systems (TABS) (heating mode);

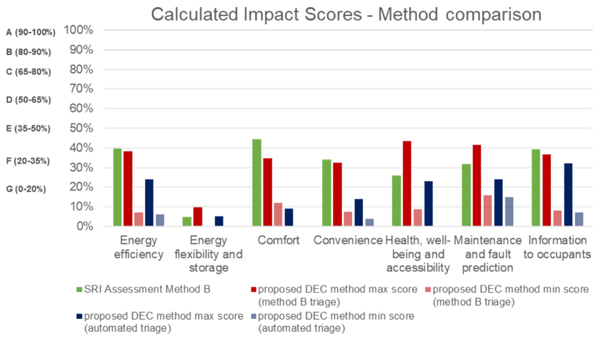
Building usage: Educational building		Multiple generators	
Building state: Renovated		Thermal energy storage not present	H1-f: Thermal Energy Storage (TES) for building heating (excluding TABS)
Location: Western Europe, United Kingdom		Hydronic system	
Total useful floor area of the building: 4,599 m^2	Domestic hot water	Non-electric with storage and no solar collectors (LTHW and gas boilers heat to indirect hot water storage calorifiers)	DHW-1a: Control of DHW storage charging (with direct electric heating or integrated electric heat pump)
Year of construction: 1915	Cooling	Hydronic system Thermal energy storage not present	C-1g: Control of Thermal Energy Storage (TES) operation
	Ventilation	Mechanical ventilation present with heat recovery	n/a
	Lighting	LED controlled via sensors for daylight, absence detectors, PIR's and local light switches.	n/a
	Dynamic envelope	Dynamic envelope features not present; roller blinds for shading; manually openable windows for natural ventilation	n/a
	Electricity	Renewable generation and storage not present	E-2: Reporting information regarding local electricity generation; E-3: Storage of (locally generated) electricity; E-4: OptimizingOptimising self-consumption of locally generated electricity
	Electrical vehicle (EV) charging	EV charging not present	Whole domain excluded from calculation
	Monitoring and control	Central monitoring and reporting system; no grid integration; no Demand-side Management (DSM) control	n/a

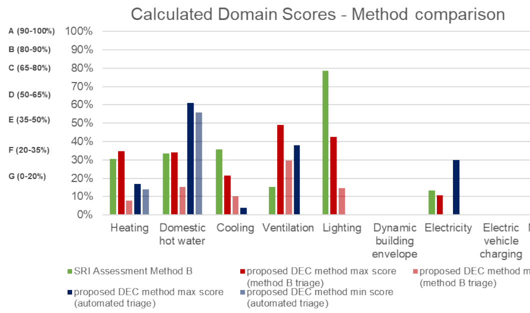
3. Results

3.1. Building level method comparison

The building-level results presentation uses two approaches. In the first, labelled 'DEC method (using method B triage)', DECs are used to assign the SRI functionality levels to the smart services ~~and~~. The triage process is based on building information as per the usual survey-based SRI method. The comparison aims to test how the automatically assigned service functionalities compare with the detailed assessment. The second approach, labelled 'DEC method (automated triage)', was fully automated with the DEC recommendation links used to assign the SRI levels *and* to carry out the triage process. The minimum and maximum SRI levels were calculated for both approaches.

For the selected building, this triage included 41 of the total 54 services of the SRI and was based on the detailed building information described previously. For the second building level test for the 'DEC method (automated triage)' 13 links were found~~,~~: 1 heating, 1 domestic hot water, 1 cooling, 3 ventilation, 0 lighting, 2 electricity, 0 dynamic envelope, 0 electric vehicle charging, and 5 monitoring and control services. Each result was also compared to the traditional survey-based detailed manual SRI calculation as per method B, labelled 'SRI assessment (method B)'. All calculations are summarised in Figure 3 and ~~Figure 4 below.~~Figure 4~~Figure 4~~ below. In terms of the impact criteria presented in Figure 3, the detailed SRI assessment scores were in the lower medium smart readiness ranges (30-50%) in 5 out of the 7 areas. Health~~,~~ and well-being scored 26~~%~~%, and energy flexibility showed the lowest score signifying that the technological systems of the building offer little in terms of energy flexibility and storage. The detailed triage method and maximum functionalities ~~follows~~follow these patterns more closely, whereas the SRI scores calculated using the minimum range of functionality appear consistently lower compared to the SRI detailed assessment. On average, the maximum score error for this comparison is +2.6% for the maximum calculation and -22.9% for the minimum, with the range of differences for specific impacts going from -9% (comfort) up to +17% (health). The fully automated calculations also showed similar patterns for the maximum functionality calculation that better represents the building smart readiness impacts compared to the minimum functionalities per service. ~~On average~~ For this comparison, the ~~maximum~~average calculation error was -11.4% and the minimum -27.4%. The average error combined for the two triage methods was +4.4% for the maximum calculation and -25.1% for the minimum calculation.





~~Figure 4: Smart readiness score per domain by calculation method. SRI ratings also sh next to the vertical axis.~~

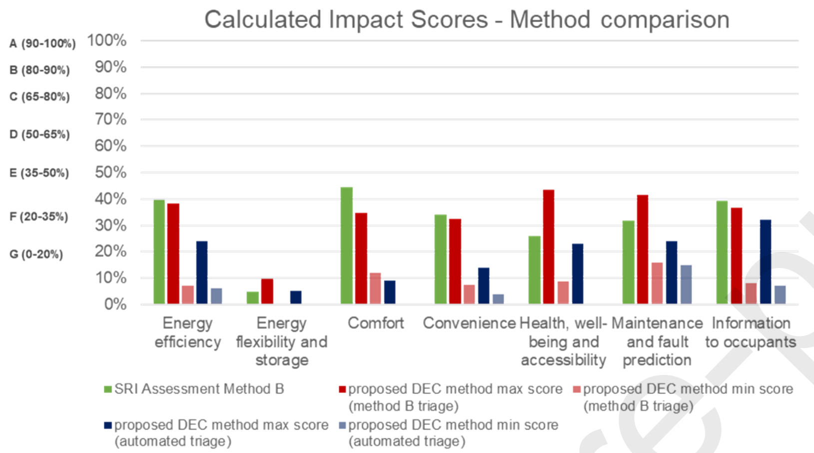


Figure 3: Smart-readiness scores per impact criteria and by calculation method. SRI ratings also shown next to the vertical axis.

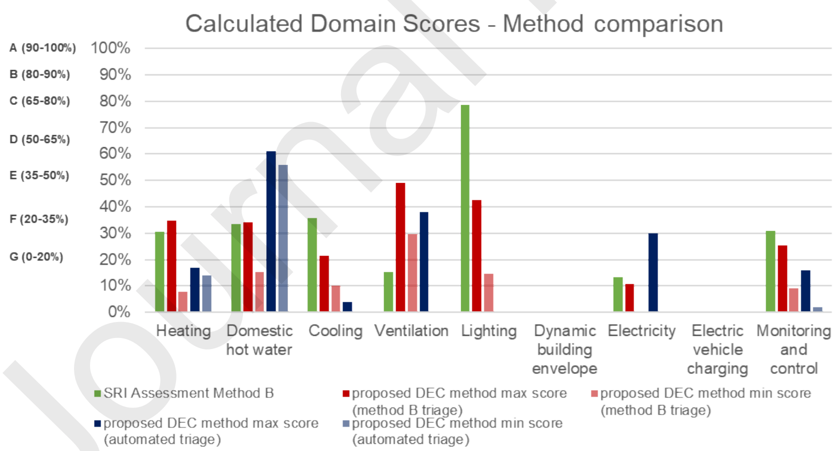


Figure 4: Smart readiness score per domain and by calculation method. SRI ratings also shown next to the vertical axis.

Regarding the assessed technological domains, ~~the~~ electric vehicle charging was omitted ~~from the calculation from the initial triage process,~~ as ~~no charging is~~it was not significantly present on the campus ~~based on the information available.~~. The remaining domains scored between 15-36% except for lighting ~~that~~, which scored very highly at 79~~%~~%, considering the available detailed design information on lighting efficiency and controls. From the comparison between the proposed DEC automated triage and the proposed DEC method B triage methods, there is less agreement in terms of technological domains as opposed to impact areas. The example of lighting shows that whole domains can be left out from the calculation if there is no mention of them in the DEC recommendations. Additionally, domain scores can be overestimated when there are limited links to services i.e~~.~~., most services are excluded, but those included score high, e.g. the domestic hot water.

For both impact scores and domains, the results show that the translation of the DEC recommendations to a minimum SRI functionality is more likely to be onerous to the calculation and underestimate the building's smart readiness, while the maximum functionality is more likely to match the standard SRI assessment.

3.2. Campus results

As explained in Section ~~2.1~~2.3, the proposed DEC-based SRI method can be integrated into an automated workflow to calculate the SRI score for large numbers of buildings. This process iterates through bulk DEC data, automatically processes the recommendations, and calculates the resulting SRI scores for each building within a sample. For this case study, the scores for 98 university campus buildings have been calculated and results are presented in ~~Figures 5, 6, 7, 8, 9.~~Figure 5,Figure 6,Figure 7 and Figure 8. A summary of the results is organised per impact criteria, domain, and the total scores per building and for the whole campus:

- **Impact scores:** Based on the DEC recommendations and for the minimum functionality per service (~~Figure 5~~Figure 6), the buildings' current smart-ready technological systems are expected to have a higher impact on maintenance and fault prediction, energy efficiency and information to occupants. The assessment showed lower impacts on occupant comfort and convenience in dealing with the current systems, while energy and flexibility and storage and health, well-being and accessibility do not appear to benefit from any of the smart-ready services. For the maximum functionality (~~Figure 6~~Figure 5), energy efficiency, information to occupants and maintenance have on average scored an SRI F rating, between 21-27%. In this case, results demonstrated a higher potential for health, well-being and accessibility impacts, scoring 18% on average across all buildings. The rest of the impact criteria, i.e. convenience, comfort and energy flexibility and storage scored the lowest in this order.
- **Domain scores:** In terms of technological domains, results are presented in Figure 7 and Figure 8, the domestic hot water scored the highest in both the minimum and maximum functionality calculations. Average scores ranged between 17-36%. This is partly expected for the campus's buildings as functionalities like DHW charging is likely to be controlled based on schedules and also likely to be monitored and reported, including retaining historical data. Similarly, lighting scored the next highest as lighting controls are becoming more common around the campus buildings. However, around half of the lighting scores remain below 15-20%, and this reflects the fact that DEC recommendations mostly suggest further control measures can be applied. Heating, DHW and lighting show the least variation between minimum and maximum functionality scores, which may suggest that the DEC recommendations are more relevant to these domains and more matches have been found.
- **Total SRI scores per building:** The total scores for all buildings are presented in Figure 9. On average, building scores ranged between 4-15% and an average G rating. Less than 25% of the buildings scored an F rating based on maximum functionality. Almost 75% of the buildings scored just 5% based on minimum functionality. Based on the findings of the building level comparison, the proposed maximum functionalities are more likely to match a detailed assessment~~,~~. Nevertheless, the overall ratings for the 98 buildings signify the large potential for smart readiness integration for the campus.
- **Campus SRI score:** While the individual buildings scores ranged between ratings of F-G, the total area-weighted average for the whole campus scored 15% (G) for the maximum functionality and 5% (G) for the minimum. Overall, in terms of smart readiness, the campus presents a large potential for smart integration to facilitate further flexibility, health and well-being benefits and comfort in line with the SRI testing commissioned by the EC showing on average scores of 19% and 34% for residential and non-residential buildings respectively.

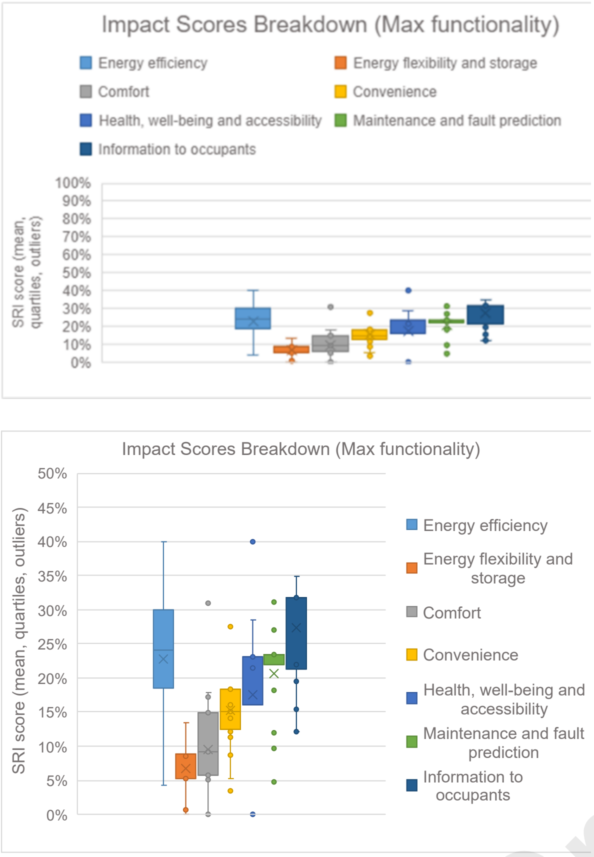


Figure 5: Impact scores calculated based on the maximum functionality per service.

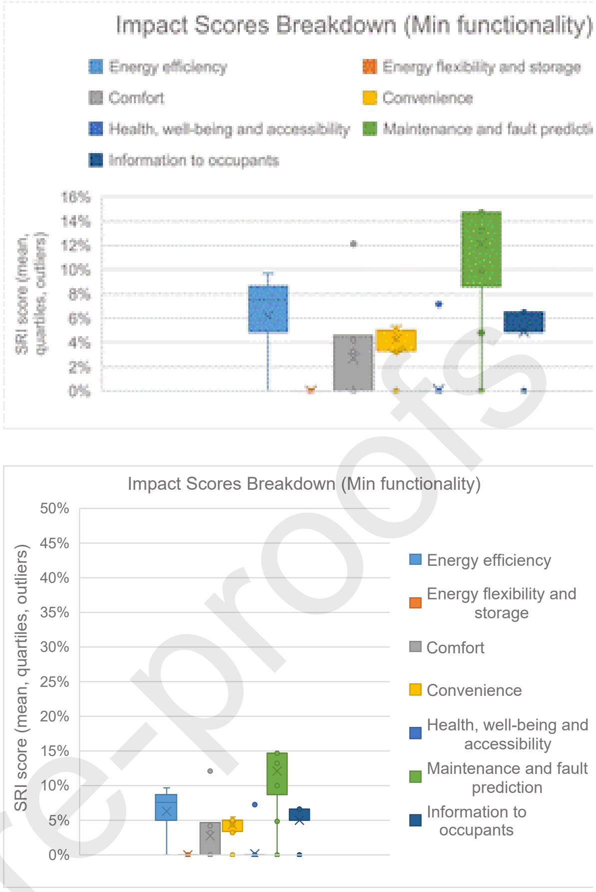


Figure 6: Impact scores calculated based on the minimum functionality per service.

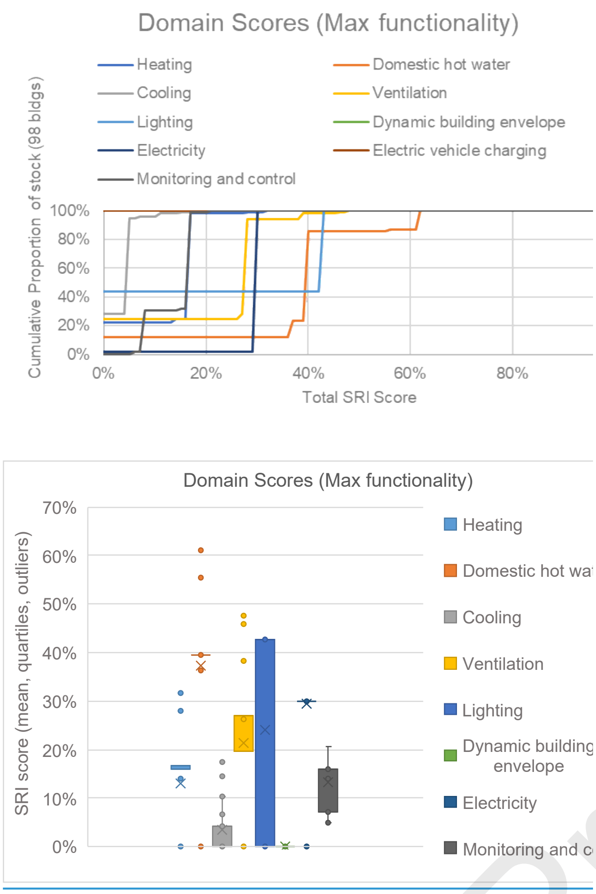


Figure 7: Domain scores based on the maximum functionality per service.

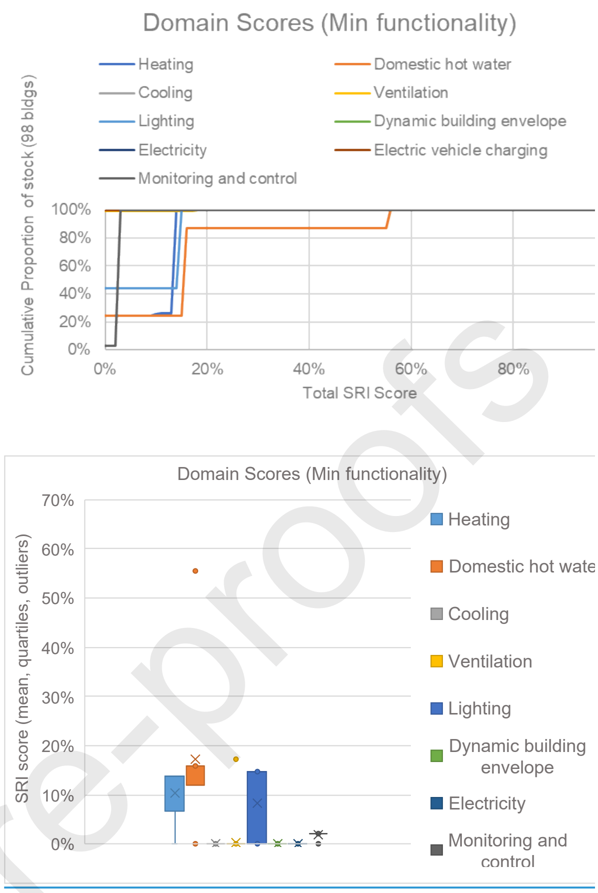
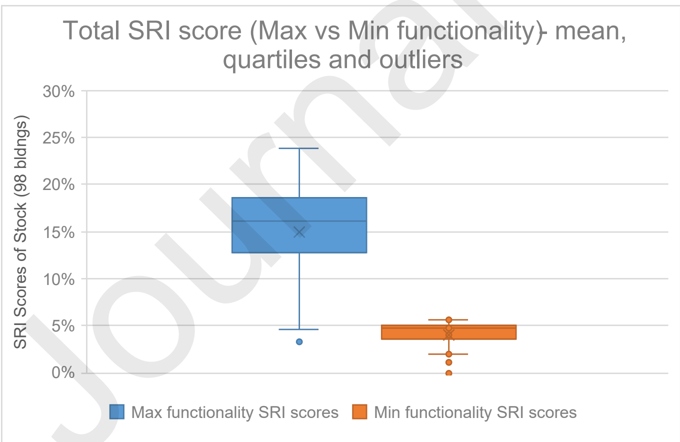


Figure 8: Domain scores based on the minimum functionality per service.



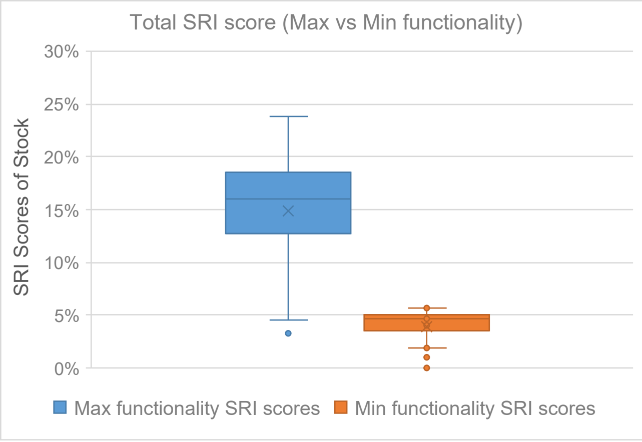


Figure 9: Standard deviation of building scores for the 98 buildings included in the study for minimum and maximum functionality per service.

3.3. Smart-ready intervention recommendations

The results demonstrate that various technological domains and impact areas offer a large potential for improvement across the university campus. In response to that and to organise the potential for smart integration measures, the SRI's key functionalities have been used as the underlying framework. The three functionalities are aggregated into: Building operation - increase energy efficiency and optimise in-use building operation; User - adapt to occupant needs; Grid - adapt to external grid signals. Table 3, summarises the SRI services with the lowest scores colour-coded as per the frequency that they came up in the DEC recommendation matches and lack thereof. These are perceived as potential smart-ready interventions that could be integrated to achieve a higher SRI score.

Table 3: Recommendations for smart-ready measures to increase the smart readiness of the case study campus.

Legend	**Services not identified in the assessment** **Services present but sparsely identified & low score** **Information from DECs widely available & low/medium score**		
	Building operation & energy efficiency	**User**	**Grid**
Heating	1. Retrofit for variable speed pump control for hydronic pumped systems with capability to respond to demand signals	1. Control of heating systems to allow for occupancy detection and room controls that communicate with the BACS.	1. Provide thermal energy storage with capability to respond to external grid signals.
	2. Electrification of heating systems where suitable.		2. Employ model predictive heating control based on load forecasting and grid signals.
	3. In case of new buildings or deep retrofits consider TABS		3. For multiple generators allow for dynamic priority control to include demand

			forecasting, carbon emissions and grid signals.
Domestic hot water	1. Retrofit for solar collectors to supplement heat generation 2. Performance reporting to allow for forecasting, predictive control and benchmarking and fault detection.		1. Automate DHW storage charging based on local renewable generation and grid information on carbon emissions, capacity etc. 2. For multiple generators allow for dynamic priority control to include demand forecasting, carbon emissions and grid signals.
Cooling	1. For chilled water systems allow for demand-based control 2. Install total interlock control so simultaneous heating and cooling can't take place 3. In case of new buildings or deep retrofits consider TABS 4. Performance reporting to allow for forecasting, predictive control and benchmarking and fault detection.	1. Control of cooling systems to allow for occupancy detection and room controls that communicate with the BACS.	1. Employ model predictive cooling control based on load forecasting and grid signals. 2. Provide thermal energy storage with capability to respond to external grid signals. 3. For multiple generators allow for dynamic priority control to include demand forecasting, carbon emissions and grid signals.
Ventilation	1. Retrofit ventilation for variable air volume systems with Variable Frequency Drive for demand-based air flow	1. Introduce local Demand Control based on air quality sensors (CO_2, VOC,..) with local flow from/to the zone regulated by dampers 2. Predictive control for the heat recovery bypass to prevent overheating	

		3. Provide real-time IAQ information to occupants. Active occupant participation in ventilation actions and maintenance based on signals (e.g. window opening)	
Lighting	1. Roll-out the upgrade of lighting systems to incorporate daylight dimming and scene-based light control	1. Roll-out the upgrade of lighting controls with occupancy detection (manual on / dimmed or auto off)	
Dynamic envelope	1. Combine automated operation of windows with the HVAC system. Combination of rooms sensor data and centralised coordination for whole building strategies like free cooling	2. Automate shading device operation based on predictive control and HVAC operation	
Electricity	1. Maximise renewable electricity generation where possible 2. Introduce fault detection for the local electricity generation systems	1. Enhance on site renewable generation monitoring to allow for forecasting, benchmarking and real-time feedback to occupants	1. Optimise self-consumption of locally generated electricity, combined with thermal energy storage and electricity storage on site and offer the possibility to feed back to the grid or microgrid island function.
EV charging	1. Introduce EV charging capacity on site for >50% of parking spaces to offer recharging points	1. Report EV charging status to the occupant and automatic charging station assignment and authorisation for the driver	1. Enable 2-way EV charging capability to allow for grid signals and desired departure time optimisation
Monitoring and control	1. Include all relevant Technical Building Systems (TBS) in a central fault detection and diagnosing system	1. Introduce occupancy detection that interacts with the relevant TBS 2. Single interface energy use reporting of all energy carriers and combining the TBS of all domains	1. HVAC operation based on predictive control and grid signals 2. Demand side management coordinated over multiple TBS

4. Discussion and conclusions

Within the context of an increasing need to understand the smart readiness of the building stock, this paper presents a methodology for automatically estimating the SRI scores for buildings ~~automatically~~ using existing bulk data from existing DEC assessments. We compare the proposed automated method (using DEC data), with a survey-based detailed smart readiness assessment of a case study building. This shows that existing DEC certificates ~~more suitably~~ can provide ~~an initial~~ insight ~~to~~into the building's smart readiness~~.~~ more suitably at a high level. When planning smart and decarbonisation upgrades, the method ~~presently provides a valuable insight to~~can determine the campus's opportunities and shortcomings ~~when planning smart and decarbonisation upgrades. Additionally~~as it links the DEC and EPC recommendations to smart ready services. Overall, the aim of this work is to understand how the SRI methodology can be implemented with minimal resources and provide an overview of focus areas in that regard rather than a technical inspection of buildings.

Compared to others in the literature that focus on single-building applications and to the standard building-level EPBD SRI methodology, the proposed method is fast, requires minimum ~~resource~~resources and therefore allows the assessment of any number of buildings. ~~In that respect, it~~The method utilises well-established building assessment data (i.e. DECs) to derive a smart readiness assessment for a portfolio of buildings. The benefits of the proposed method lie in streamlining the data collection and calculation process. While a much deeper understanding of all the building-level technical systems is required to carry out the SRI assessment, with this method, an initial overview of the smart readiness of a campus stock is achieved with minimal pre-existing information. ~~This initial assessment can therefore be used by~~ Large portfolio managers can therefore use this initial assessment to scope areas and buildings to focus their smart transition and decarbonisation efforts. In summary, the advantages of the proposed DEC method are described in Table 4.

Table 4: Method comparison for proposed DEC automated calculation and the SRI Detailed Method A.

Comparison	Campus level assessment: proposed method	Building level assessment: standard method
Data collection	Bulk DEC download by address	Data collection, ~~incl.~~including as-built system specifications and operational manuals. Site visit by the assessor mandatory if certification is sought.
Triage	Based on recommendations	Based on building data assessment
Building SRI calculation	Automated	Need to assign scores to each service
Campus SRI calculation	Area weighted SRI score for the campus stock	No recommendation

On the other hand, the limitations of the proposed method ~~on the other hand~~ stem from the fact that DECs (and other similar schemes, like EPCs) are focused on building energy efficiency and therefore lack links to some of the SRI's domains. Although the main DEC recommendation categories match ~~to~~

the SRI domains~~ (see Table 1), DEC~~, EC recommendations mostly focus on low-carbon and energy measures ~~with reference to~~concerning control systems that provide insight ~~to~~into some ~~of the~~ SRI services. An example of this is the heating system recommendations, which mostly focus on energy efficiency and low-carbon alternatives~~, they do~~; however, they also touch on controls and reporting of performance. Importantly, both schemes do not sufficiently address issues like occupant environmental control, indoor environmental quality, and any potential energy rebound effects – occupants being able to overcompensate on comfort when savings are made. Although occupant environmental control is ~~given a high rating~~rated highly as a smart-ready functionality, it is not~~ however~~ linked to a measurable comfort indicator or energy use.

To maximise the links between the two assessment and certification methods and improve the potential to use DEC data in this way, the DEC recommendations could be ~~expanded~~centrally reformed to include all the smart-ready domains. As other research suggests, a hybrid version of the schemes integrating both into one could also be the answer to drive the integration of smartness to the building level in line with the European Union's goals and enhance the way energy efficiency is monitored.

Additionally, a limitation of this work derives from the fact that the recommendation and smart readiness links have been made using the ~~researcher's~~researchers' judgment. The SRI process inherently allows for subjectivity due to the fact that smart-ready service functionalities are descriptive ~~[23,44,45]~~[29,31,51]. The same is true for the AR recommendations. However, any potential integration of the two methods could benefit from a more rigorous approach overseen by the regulatory authorities responsible for them and further standardisation of the proposed method. As presented, however, the proposed method allows for flexibility to amend links and the assigned functionality levels.

In terms of further work, around half of the campus buildings were excluded from the study as they did not hold a DEC. The assessment can be further expanded to include EPCs and their associated recommendations. DECs were initially selected as the most common and up-to-date assessments due to the scheme's application to large public non-domestic buildings. In contrast, EPCs represent the designed building and are only updated when major changes are undertaken in the building affecting its energy use or properties are sold or rented. Extending the method to EPCs~~, however,~~ would allow any type of building to be assessed and is therefore considered beneficial. ~~All in all~~Overall, it is recognised that the aggregation of building SRI scores to a campus-wide score does not bring forward potential interactions between the assessed buildings. However, this is also a limitation inherent in the SRI calculation since on-site electricity generation and storage are investigated within the building boundaries while harmonisation with the grid is considered.

Finally, the research aims to expand the scope of this analysis to the ~~whole UK~~ higher education sector in England and Wales. With a larger sample of buildings, the analysis is expected to surface potential links between typology and building use and SRI scores and domains.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have influenced the work reported in this paper.

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APPENDIX A

Table A 1: Full table of DEC recommendation – SRI smart service links

DEC Recommendation		SRI Links	
Code	Text	Number	Domain(s) min/max levels
AE3	Consider installing building mounted solar water heating.	0	(excludes smart service DHW-1d)
AE10	Consider a small-scale Tri-Generation system as an alternative to conventional separate boiler and chiller systems.	1	E-5 (min: 0, max: 0)
BF5	Consider applying reflective coating to windows and/or fit shading devices to reduce unwanted solar gain.	1	DE-1 (min: 0, max: 0)
BF16	Consider installing automatic closers to loading bay goods doors or shutters.	1	DE-2 (min: 0, max: 0)
CON2	Engage experts to review the HVAC control systems settings and propose alterations and/or upgrades and adjust to suit current occupancy patterns.	5	H-1a (min: 0, max: 3), C-1a (min: 0, max: 3), V-1a (min: 0, max: 1), V-1c (min: 0, max: 1), MC-9 (min: 0, max: 1)
CON10	Seek to minimise simultaneous operation of heating and cooling systems.	2	C-1f (min: 0, max: 1), MC-3 (min: 0, max: 1)
CON15	Consider installing weather compensator controls on heating and cooling systems.	3	H-1c (min: 0, max: 0), C-1c (min: 0, max: 0), MC-30 (min: 0, max: 2)
CON16	If natural ventilation does not provide adequate cooling during the day, consider introducing external air at night to cool the internal space.	0	-(excludes V-3)

CON17	Consider installing timer controls to energy consuming plant and equipment and adjust to suit current building occupancy.	4	H-1a (min: 0, max: 2), C-1a (min: 1, max: 2), V-1a (min: 0, max: 1), V-1c (min: 0, max: 1)
CON18	Consider upgrading major time controls to include optimum start/stop.	2	C-1a (min: 0, max: 3), V-1a (min: 0, max: 1)
CON20	Consider introducing variable speed drives (VSD) for fans, pumps and compressors.	3	H-1d (min: 0, max: 2), H-2b (min: 0, max: 1), C-1d (min: 0, max: 2)
CON23	Consider fitting zone controls to reduce over and under heating where structure, orientation, occupation or emitters have different characteristics.	4	H-1a (min: 0, max: 1), MC-3 (min: 0, max: 1), MC-9 (min: 0, max: 1), MC-30 (min: 0, max: 1)
HS18	Consider installing interlocks between heating systems and loading bay or vehicle access doors.	1	MC-30 (min: 0, max: 1)
HW19	Engage experts to propose specific measures to reduce hot water wastage and plan to carry this out.	4	DHW-1a (min: 0, max: 1), DHW-1b (min: 0, max: 1), DHW-2b (min: 0, max: 1), DHW-3 (min: 0, max: 1)
OM15	It is recommended that energy management techniques are introduced. These could include efforts to gain building users commitment to save energy, allocating responsibility for energy to a specific person (champion), setting targets and monitoring.	3	H-3 (min: 1, max: 2), DHW-3 (min: 1, max: 2), V-6 (min: 0, max: 2)
SP3	Consider installing automated controls and monitoring systems to electrical equipment and portable appliances to minimise electricity waste.	2	E-12 (min: 0, max: 2), MC-13 (min: 0, max: 1)
SP24	Enable power save settings and power down management on computers and associated equipment.	2	E-4 (min: 0, max: 1), MC-29 (min: 0, max: 0)

V1	Engage experts to propose and set up a ventilation servicing and maintenance regime and implement it.	1	MC-4 (min: 0, max: 0)
V8	Consider whether the humidity control system is essential and/or consider re-setting to more efficient parameters where close control is not critical.	1	V-3 (min: 0, max: 0)
V10	Consider with experts whether it would be worthwhile installing variable speed fans and volume control devices to the ventilation system.	2	V-1c (min: 0, max: 1), V-2d (min: 0, max: 1)
X1	The current metering provisions do not enable production of a specific and reasonably accurate Operational Rating for this building. It is recommended that meters be installed and a regime of recording data be put in place. CIBSE TM 39 gives guidance on this.	4	H-3 (min: 0, max: 1), DHW-3 (min: 0, max: 1), C-3 (min: 0, max: 1), MC-13 (min: 0, max: 1)
X4	Review staffing arrangements and set up formal systems for delegating authority for Building Energy Management System alterations and/or temporary overrides.	1	MC-29 (min: 0, max: 0)
X8	Ensure building occupants understand when the various ventilation and cooling modes of the mixed mode ventilation system are in operation to avoid windows being opened when mechanical cooling is on.	3	V-3 (min: 1, max: 2), V-6 (min: 0, max: 1), DE-2 (min: 0, max: 0)
X13	Engage experts to review the building lighting strategies and propose alterations and/or upgrades to daylighting provisions, luminaires and their control systems and an implementation plan.	2	L-1a (min: 0, max: 1), L-2 (min: 1, max: 2)
X25	Consider introducing a system of regular checks of Heating, Ventilation and Air Conditioning (HVAC) time and temperature settings and provisions to prevent unauthorised adjustment.	2	MC-29 (min: 0, max: 0), MC-30 (min: 1, max: 1)

Declaration of interests

☒ The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

☐ The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: