ALMA MATER STUDIORUM
UNIVERSITÀ DI BOLOGNA

DEPARTMENT OF
CIVIL, CHEMICAL, ENVIRONMENTAL AND MATERIALS ENGINEERING

SECOND CYCLE MASTER'S DEGREE IN EARTH RESOURCES ENGINEERING

DEVELOPMENT OF METHOD FOR CALCULATION OF BUILDING AUTOMATION INDEX RELATING TO ENERGY USE AND REDUCTION BASED ON BUILDING SMARTNESS AND ITS POTENTIAL APPLICATIONS

Supervisor

Prof. Alessandra Bonoli

Defended by

Ava Marini Mennin

Graduation Session December 2025

Academic Year 2024/2025

Acknowledgements

I would like to thank my family, my mom, my dad, and my brother, for supporting me unconditionally in my decision to effectively change careers and go back to school overseas to study an almost entirely new field. Thank you for always seeking to understand me and what I'm trying to do. Thank you to my friends and the wonderful people that I've met here in Bologna who supported me during my studies and helped me find stability in a new city so far from home.

I would like to thank the University of Bologna and all the incredible professors that I had the opportunity to study under for providing me with an inspiring and challenging education. Specifically, I'd like to thank my thesis supervisor Professor Bonoli. As one of the first professors I had at the beginning of this program, she helped to grow my passion to serve humanity and the planet through engineering. Finally, I want to thank Diego Rattazzi, Paolo Finocchi, Fabrizio Tavaroli, and the rest of the sustainability team at RINA Consulting that provided me with the opportunity to apply my education to real world sustainability solutions and provided me with so much guidance.

Contents

List of Figures

List of Tables

Abstract

This thesis describes a new, efficient method for rating the automated building functions for both existing buildings and proposed new construction for the purpose of lowering energy consumption. Excessive energy use of buildings and large-scale structures, particularly older ones, is a significant problem that needs to be addressed within the European Union. The introduction of smart technologies, those designed to react to conditions affecting human health, safety, and comfort and provide an automated response to the problem, is one proposed means of combatting this issue. In preparation for this thesis, a ten-week internship was carried out at RINA Consulting in Genova, Italy with the Sustainability Team as a sustainability intern. During this period the use of the calculated smartness of a building's systems, which is determined by a pre-existing process performed entirely in Microsoft Excel, as a means of rating the Building Automation and Control Systems (BACS) was explored. Once a clear method of calculation was established, this algorithm was translated into a user-friendly app developed in MATLAB App Designer. The purpose of which was to serve as a means of quickly and efficiently calculating a score to be assigned to the BACS that could be meaningfully used to make changes to the building to increase its energy efficiency and lower energy consumption and costs. As a final step, the building headquarters of the Regional Council of Lazio in Rome, Italy whose energy systems RINA was tasked with evaluating as part of an ongoing renovation process was used as an means of showing the algorithm's capability and applications. While the results of the study determined that this building currently has a very low rating regarding both smartness and capability of its BACS, it also identified specific problem areas that will allow for clear, meaningful changes to be made going forward with this project and others like it.

1 Introduction

In a time when all industries globally should be seeking to lower carbon emissions, one sector stands out significantly: building and construction. The construction industry is responsible for an estimated 35% of carbon emissions within the European Union and 37% globally [1][2]. Obviously construction is an as an industry will never be obsolete, so more sustainable practices regarding demolition and use of materials, for example are required. The practice of demolishing a building just to construct a new one in its place contributes significantly to these emissions but is justifiable when an existing building is energy inefficient enough that a proposed solution of replacing it with new construction that abides by energy efficient practices and materials would ultimately have a lower environmental impact long term. One method of supporting this is through the automation of the building systems and the introduction of smart technologies that seek to reduce energy use and cost. In the case where new construction is unavoidable, the practice of implementing these systems still allow for decreased energy use. These solutions are particularly desirable within the EU and other countries where buildings and other structures have been standing for significant periods, have survived significant historical events, or have other cultural significance. Even in more recent history, 85% of buildings in the EU were built before 2000, and 75% have an energy performance considered to be poor [3]. This is to say that the implementation of better energy systems is particularly desirable in the case where demolishing and replacing a building are, simply, not an option. Retrofitting these buildings with systems that allow for a decrease in energy use is a proposed way to ensure longevity and continued use.

In preparation for this thesis, an internship at RINA Consulting in Genova, Italy as a sustainability intern for the Sustainability Team was conducted over the course of ten weeks. During this time, EU initiatives to reduce the carbon footprint and increase energy efficiency of both existing buildings and new construction related to the automated functions of buildings were studied to support this thesis work. More specifically, two such indices and a meaningful connection between the two were selected for further research: the Smart Readiness Indicator (SRI) developed under the European Commission's 2024 Energy Performance of Buildings Directive (EPBD) and a rating system applied to the Building Automation and Control Systems (BACS) developed by the European Building Automation and Controls Association (EUBAC). The BACS directly references the technology and systems used to automate HVAC, lighting, and other building systems that get assigned an alphabetic value A-D (a system established by Standard UNI EN ISO 52120-1:2022) [4]. Alternatively, the SRI is a calculated numerical score from 0-100% that rates the capabilities and the smartness of the same building systems [5]. While both indicators measure separate aspects, they are inextricably linked. This thesis will further explore and establish an efficient method of connecting the two concepts, using the SRI to evaluate the BACS class.

The SRI is computed by a pre-existing process developed by the EPBD. The research for this thesis utilizes a Microsoft Excel spreadsheet that implements this algorithm. This procedure entails assigning a score or functionality level to a number of services related to the smartness, the climate associated with the location, the building's use, and the size of the building. This spreadsheet is freely available for research, business, and personal purposes [5]. The BACS, on the other hand, while it relies on similar criteria, has a more complex calculation process that is not as readily available to the public. Both concepts will be explained in greater detail in the following sections.

Drawing a direct connection between these two criteria serves several purposes. The first being that it allows for a calculation of the BACS class to be as available as the calculation of the SRI score. The BACS scale and accompanying information provide a means of calculating the energy saving potential when positive changes regarding the building's technology are made, but the SRI does not. Creating a conversion of the SRI score to the BACS class allows this energy saving potential to be relevant within the scope of the SRI. More specifically, it shows what changes to the smartness of the building will significantly reduce energy use.

Section 7 below will explore a case study of the systems of the building headquarters of the regional council of Lazio in Rome, Italy that RINA was tasked with analysing. It will explore how the data from a given energy analysis and report of the general building information can be used to draw meaningful conclusions about the smartness, automated functions, and ultimately how energy consumption can be reduced in a building.

2 Smart Technologies and Their Potential Applications

Smart technologies are technologies that operate based on sensors and gathered data to automatically perform a desired function based on a developed, appropriate response to a situation [6]. They are designed to anticipate the needs of the user in many scenarios including safety and healthcare, to name a few. For example, sensors that detect seismic activity and relay to building systems to activate procedures and technology that protect the building is an example of smart technology [7]. This is an instance where smart technology is used to protect the building itself preventing the need for reconstruction but mostly for the protection of the people inside the building and in the vicinity. The idea of the introduction of systems such as these is not to replace human involvement, but rather maximize efficiency of systems to allow humans to thrive in an environment that is comfortable and safe.

To reiterate, systems such as these don't replace the role that people play in existing practices, but rather perform instantaneous functions that people were not necessarily tasked with in the first place. In the context of buildings, automatically adjusting the building systems to serve the occupants can significantly affect their well-being. A study out of Washington State University in Pullman, Washington, USA shows a connection between adequate lighting and ventilation with not only occupant comfort and health, but also overall productivity [8]. Furthermore, a study conducted by Yeonsei University in Seoul, South Korea suggests that in the context of an office space adequate lighting that is overpowering or too dim directly impact cognitive performance [9]. A potential solution to mitigate harshness or dullness of lighting that affects a building occupant's well-being is a smart system that adjusts to an adequate comfort level based on several factors such as the hour of the day, the time of year, and the weather of a given day. When implemented thoughtfully and intentionally, these systems seek to replace outdated technology and don't suggest that human involvement and impact is outdated.

While these benefits described are a factor in the implementation of smart systems, within this context and the scope of this study the purpose of smart technologies is to regulate energy usage of nine of a building's systems, more specifically its heating, domestic hot water, cooling, ventilation, lighting, dynamic building envelope, electricity, electric vehicle charging, and monitoring/control. This study will primarily focus on the first five. For example, a smart lighting system would adjust the lighting of a given space based on the time of day and position of the sun or the detected visibility on a more overcast day versus a sunnier one, or a smart ventilation system would operate at a higher or lower capacity based on the number of occupants of a room, the humidity levels, and temperature [10]. The anticipated result is lower energy costs and lower energy usage in addition to the health and comfort of a given building's occupants.

An example of an especially smart building is The Edge in the Netherlands. This is the name given to the Deloitte headquarters in Amsterdam. It received a 98.4% Building Research Establishment Environmental Assessment Method (BREEAM), another index developed to measure sustainability and carbon emissions of buildings, and uses 70% less energy than the average building [11][12]. The result of adding smart functions to the building directly impacted the energy efficiency of the systems but also the well-being of the employees. Figure 1 below shows an image of the building.

Figure 1: The Edge Deloitte Headquarters in Amsterdam, Netherlands [13]

This building has become so energy efficient and cost effective through the use of sensors throughout the building that monitor occupancy, temperature, seasonal climate data, and other factors. This allows for a smart system to detect when to power the HVAC, lighting, and other building systems at what time and how powerfully. This also allows for lowered use while maintaining building comfort and safety for the occupants. The less frequent use of equipment also allows for the technology and machinery to be replaced far less frequently. Though potentially small, this reduces the carbon emissions associated with production of this equipment. This is to say that when done successfully, smart technology has the potential to disrupt existing practices.

3 The Smart Readiness Indicator

The SRI is an index developed by the European Union's Energy Performance of Buildings Directive (EPBD) whose purpose is to measure the "smartness" of a building. Smartness in this context is a term used to define a building's "ability to sense, interpret, communicate and actively respond in an efficient manner to changing conditions in relation to the operation of technical building systems, the external environment (including energy grids) and the demands from building occupants" [5]. The primary goals of this indicator are to:

- optimize energy efficiency and overall in-use performance
- adapt their operation to the needs of the occupant
- adapt to signals from the grid (for example energy flexibility) (cite source)

The capability of each indicated service relating to the smartness is assessed based on the following impacts.

- energy efficiency
- energy flexibility and storage
- comfort
- convenience
- health, well-being and accessibility
- maintenance and fault prediction
- information to occupants [5]

It serves as a means of quantifying how smart a building is. It allows for both strong points and gaps in smartness to be identified. Each of these goals and impacts seek to accomplish this.

3.1 SRI Frameworks

Because the concept of the SRI was only formally introduced in 2018, at this point in time, there are no minimum SRI requirements that a building needs to meet. This concept is officially still officially in a testing phase, and EU nations may choose to participate or not in experimenting with the potential applications of the SRI. However, it is anticipated that by June 30, 2026 the EPBD must submit a report to European Parliament on the outcome of this testing phase, and the following year Parliament will adopt regulations to be enforced regarding the SRI. Having said this, each country may adopt their own standards and own list of necessary smart ready services based on the results of the testing phase [5]. So, although there are no incentives, financial or otherwise, associated with this exploration, it serves each nation involved to begin this process before guidelines are regulations are implemented. The sixteen countries within the EU that have begun to take part in the testing phase of the SRI in anticipation of this 2027 Regulation are Austria, Belgium (Flanders), Bulgaria, Croatia, Cyprus, Czech Republic, Denmark, Finland, France, Germany, Greece, Italy, Poland, Portugal, Slovenia and Spain [14]; however, this thesis will primarily focus on the work being done within Italy as the research in preparation was conducted at an Italian company and the case study in a following section pertains to a building located in Italy. Figure 2 below shows the generalized workflow associated with researching and implementing the SRI.

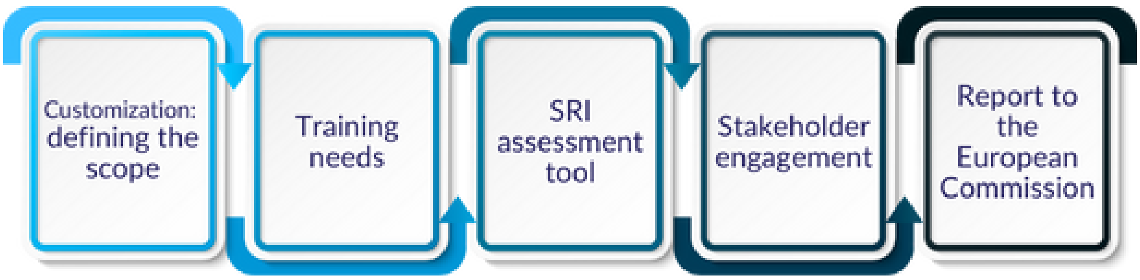


Figure 2: Process of the Implementation of the SRI [15]

Within Italy this testing phase is being led by the Ministry of Environment and Energy Security with the support of National Agency for New Technologies, Energy and Sustainable Economic Development (ENEA) who implemented a period of 12 months starting in March of 2025 [14]. This was executed after the practical work done in support of this thesis was completed. The aim is to explore the application of the SRI in different climates, building types, and building sizes to determine the efficacy of the implementation of the SRI.

3.2 Calculation of the SRI

As mentioned in a previous section, the calculation of the SRI is performed within a Microsoft Excel spreadsheet developed by the European Union's Energy Performance of Buildings Directive. There are other online means of calculation, but the use of an excel spreadsheet was the option that was best for the purpose of this research. The exact method of this calculation is quite detailed, and the step-by-step process of which is not relevant to the discussion in this thesis. It relies on the input of a ranking that corresponds to a specific building "smart ready service", specified in the tables shown below in Sections 3.3.1-3.3.5. It also relies on the type of building being analyzed (residential vs. non-residential and an accompanying sub-category for either) as well as the country where the building is located. These specifications exist because both the purpose and the general climate associated with the location of the site impact the results. For example, a building located in the colder, darker climates of northern Europe that experience polar night during the winter may weigh heating and lighting more heavily, while one in the warmer, more humid climates of southern Europe that experience extreme hot temperatures during the summer months may rely more heavily on cooling and ventilation. This is accounted for by a series of domain weightings relating to the nine domains specified as well as impact weightings based on the impacts specified in Section 3. These are established in the SRI spreadsheet. An example of the domain weightings and impact weightings are replicated below in Tables 66-69 in Section 7 that discusses a case study that utilizes this method.

The SRI smart ready services themselves are measured numerically from a minimum of 0 to a maximum of 4. This distinction is made because not all smart ready services have the same number of possible functionality levels, meaning some criteria have levels 0-2, some have levels 0-3, and some have levels 0-4. The results are a percent value for each of the nine domains, a percent value for each of the seven impacts, and an overall percentage or a score accompanied by an alphabetic class value in the form of two bar graphs. An example of which is shown below in Section 7.

3.3 Smart Ready Services Relevant to this Study

Tables 1-33 have been generated using the SRI smart ready services and the possible functionality levels taken directly from the SRI spreadsheet developed by the EPBD. Only five of the nine services are shown, as these are the five associated with the research conducted.

3.3.1 Heating Tables

Tables 1-10 below show the individual SRI functionality levels for each of the smart ready services within the heating domain. The specific services relevant to the heating domain can be found in the titles of each of the following Tables 1-10. These services outline how heat is emitted based on the detection of room occupancy, how the heat pumps communicate with each other, and how the heating systems communicate with systems outside the building.

Table 1: H-1a: Heat emission control [16]

Level 0	No automatic control
Level 1	Central automatic control (e.g. central thermostat)
Level 2	Individual room control (e.g. thermostatic valves, or electronic controller)
Level 3	Individual room control with communication between controllers and to BACS
Level 4	Individual room control with communication and occupancy detection

Table 2: H-1b: Emission control for TABS (heating mode) [16]

Level 0	No automatic control
Level 1	Central automatic control
Level 2	Advanced central automatic control
Level 3	Advanced central automatic control with intermittent operation and/or room temperature feedback control

Table 3: H-1c: Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks [16]

Level 0	No automatic control
Level 1	Outside temperature compensated control
Level 2	Demand based control

Table 4: H-1d: Control of distribution pumps in networks [16]

Level 0	No automatic control
Level 1	On off control
Level 2	Multi-stage control
Level 3	Variable speed pump control (pump unit (internal) estimations)
Level 4	Variable speed pump control (external demand signal)

Table 5: H-1f: Thermal Energy Storage (TES) for building heating (excluding TABS) [16]

Level 0	Continuous storage operation
Level 1	Time-scheduled storage operation
Level 2	Load prediction based storage operation
Level 3	Heat storage capable of flexible control through grid signals (e.g. DSM)

Table 6: H-2a: Heat generator control (all except heat pumps [16]

Level 0	Constant temperature control
Level 1	Variable temperature control depending on outdoor temperature
Level 2	Variable temperature control depending on the load (e.g. depending on supply water temperature set point)

Table 7: H-2b: Heat generator control (for heat pumps) [16]

Level 0	On/Off-control of heat generator
Level 1	Multi-stage control of heat generator capacity depending on the load or demand (e.g. on/off of several compressors)
Level 2	Variable control of heat generator capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)
Level 3	Variable control of heat generator capacity depending on the load AND external signals from grid

Table 8: H-2d: Sequencing in case of different heat [16]

Level 0	Priorities only based on running time
Level 1	Control according to fixed priority list: e.g. based on rated energy efficiency
Level 2	Control according to dynamic priority list (based on current energy efficiency, carbon emissions and capacity of generators, e.g. solar, geothermal heat, cogeneration plant, fossil fuels)
Level 3	Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions and capacity of generators)
Level 4	Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions, capacity of generators AND external signals from grid)

Table 9: H-3: Report information regarding heating system [16]

Level 0	None
Level 1	Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy usage)
Level 2	Central or remote reporting of current performance KPIs and historical data
Level 3	Central or remote reporting of performance evaluation including forecasting and/or benchmarking
Level 4	Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection

Table 10: H-4: Flexibility and grid [16]

Level 0	No automatic control
Level 1	Scheduled operation of heating system
Level 2	Self-learning optimal control of heating system
Level 3	Heating system capable of flexible control through grid signals (e.g. DSM)
Level 4	Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection

3.3.2 Domestic Hot Water Tables

Tables 11-15 below show the individual SRI functionality levels for each of the smart ready services within the domestic hot water domain. The specific services relevant to the domestic hot water domain can be found in the titles of each of the following Tables 11-15. These services outline how hot water is stored and generated and how multiple systems potentially communicate with each other.

Table 11: DHW-1a: Control of DHW storage charging (with direct electric heating or integrated electric heat pump) [16]

Level 0	Automatic control on / off
Level 1	Automatic control on / off and scheduled charging enable
Level 2	Automatic control on / off and scheduled charging enable and multi-sensor storage management
Level 3	Automatic charging control based on local availability of renewables or information from electricity grid (DR, DSM)

Table 12: DHW-1b: Control of DHW storage charging (using hot water generation) [16]

Level 0	Automatic control on / off
Level 1	Automatic control on / off and scheduled charging enable
Level 2	Automatic on/off control, scheduled charging enable and demand-based supply temperature control or multi-sensor storage management
Level 3	DHW production system capable of automatic charging control based on external signals (e.g. from district heating grid)

Table 13: DHW-1d: Control of DHW storage charging (with solar collector and supplementary heat generation) [16]

Level 0	Manual selected control of solar energy or heat generation
Level 1	Automatic control of solar storage charge (Prio. 1) and supplementary storage charge
Level 2	Automatic control of solar storage charge (Prio. 1) and supplementary storage charge and demand-oriented supply or multi-sensor storage management
Level 3	Automatic control of solar storage charge (Prio. 1) and supplementary storage charge, demand-oriented supply and return temperature control and multi-sensor storage management

Table 14: DHW-2b: Sequencing in case of different DHW generators [16]

Level 0	Priorities only based on running time
Level 1	Control according to fixed priority list: e.g. based on rated energy efficiency
Level 2	Control according to dynamic priority list (based on current energy efficiency, carbon emissions and capacity of generators, e.g. solar, geothermal heat, cogeneration plant, fossil fuels)
Level 3	Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions and capacity of generators)
Level 4	Control according to dynamic priority list (based on current AND predicted load, energy efficiency, carbon emissions, capacity of generators AND external signals from grid)

Table 15: DHW-3: Report information regarding domestic hot water performance [16]

Level 0	None
Level 1	Indication of actual values (e.g. temperatures, submetering energy usage)
Level 2	Actual values and historical data
Level 3	Performance evaluation including forecasting and/or benchmarking
Level 4	Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection

3.3.3 Cooling Tables

Tables 16-25 below show the individual SRI functionality levels for each of the smart ready services within the cooling domain. The specific services relevant to the cooling domain can be found in the titles of each of the following Tables 16-25. These services outline the cooling emission, the distribution of cold air, and how these systems communicate with each other.

Table 16: C-1a: Cooling emission [16]

Level 0	No automatic control
Level 1	Central automatic control
Level 2	Individual room control
Level 3	Individual room control with communication between controllers and to BACS
Level 4	Individual room control with communication and occupancy detection

Table 17: C-1b: Emission control for TABS (cooling mode) [16]

Level 0	No automatic control
Level 1	Central automatic control
Level 2	Advanced central automatic control
Level 3	Advanced central automatic control with intermittent operation and/or room temperature feedback control

Table 18: C-1c: Control of distribution network chilled water temperature (supply or return) [16]

Level 0	Constant temperature control
Level 1	Outside temperature compensated control
Level 2	Demand based control

Table 19: C-1d: Control of distribution pumps in networks [16]

Level 0	No automatic control
Level 1	On off control
Level 2	Multi-Stage control
Level 3	Variable speed pump control (pump unit (internal) estimations)
Level 4	Variable speed pump control (external demand signal)

Table 20: C-1f: Interlock: avoiding simultaneous heating and cooling in the same room [16]

Level 0	No interlock
Level 1	Partial interlock (minimising risk of simultanieus heating and cooling e.g. by sliding setpoints)
Level 2	Total interlock (control system ensures no simultaneous heating and cooling can take place)

Table 21: C-1g: Control of Thermal Energy Storage (TES) operation [16]

Level 0	Continuous storage operation
Level 1	Time-scheduled storage operation
Level 2	Load prediction based storage operation
Level 3	Cold storage capable of flexible control through grid signals (e.g. DSM)

Table 22: C-2a: Generator control for cooling [16]

Level 0	On/Off-control of cooling production
Level 1	Multi-stage control of cooling production capacity depending on the load or demand (e.g. on/off of several compressors)
Level 2	Variable control of cooling production capacity depending on the load or demand (e.g. hot gas bypass, inverter frequency control)
Level 3	Variable control of cooling production capacity depending on the load AND external signals from grid

Table 23: C-2b: Sequencing of different cooling generators [16]

Level 0	Priorities only based on running times
Level 1	Fixed sequencing based on loads only: e.g. depending on the generators characteristics such as absorption chiller vs. centrifugal chiller
Level 2	Dynamic priorities based on generator efficiency and characteristics (e.g. availability of free cooling)
Level 3	Load prediction based sequencing: the sequence is based on e.g. COP and available power of a device and the predicted required power
Level 4	Sequencing based on dynamic priority list, including external signals from grid

Table 24: C-3: Report information regarding cooling system performance [16]

Level 0	None
Level 1	Report information regarding cooling system performance Central or remote reporting of current performance KPIs (e.g. temperatures, submetering energy usage)
Level 2	Central or remote reporting of current performance KPIs and historical data
Level 3	Central or remote reporting of performance evaluation including forecasting and/or benchmarking
Level 4	Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection

Table 25: C-4: Flexibility and grid interaction [16]

Level 0	No automatic control
Level 1	No automatic control
Level 2	Self-learning optimal control of cooling system
Level 3	Cooling system capable of flexible control through grid signals (e.g. DSM)
Level 4	Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control)

3.3.4 Ventilation Tables

Tables 26-31 below show the individual SRI functionality levels for each of the smart ready services within the ventilation domain. The specific services relevant to the ventilation domain can be found in the titles of each of the following Tables 26-31. These services outline how air is supplied and circulated in a given space.

Table 26: V-1a: Supply air flow control at the room level) [16]

Level 0	No ventilation system or manual control
Level 1	Clock control
Level 2	Occupancy detection control
Level 3	Central Demand Control based on air quality sensors (CO2, VOC, humidity, ...)
Level 4	Local Demand Control based on air quality sensors (CO2, VOC,...) with local flow from/to the zone regulated by dampers

Table 27: V-1c: Air flow or pressure control at the air handler level [16]

Level 0	No automatic control: Continuously supplies of air flow for a maximum load of all rooms
Level 1	On off time control: Continuously supplies of air flow for a maximum load of all rooms during nominal occupancy time
Level 2	Multi-stage control: To reduce the auxiliary energy demand of the fan
Level 3	Automatic flow or pressure control without pressure reset: Load dependent supplies of air flow for the demand of all connected rooms.
Level 4	Automatic flow or pressure control with pressure reset: Load dependent supplies of air flow for the demand of all connected rooms (for variable air volume systems with VFD).

Table 28: V-2c: Heat recovery control: prevention of overheating [16]

Level 0	Without overheating control
Level 1	Modulate or bypass heat recovery based on sensors in air exhaust
Level 2	Modulate or bypass heat recovery based on multiple room temperature sensors or predictive control

Table 29: V-2d: Supply air temperature control at the air handling unit level [16]

Level 0	No automatic control
Level 1	Constant setpoint: A control loop enables to control the supply air temperature, the setpoint is constant and can only be modified by a manual action
Level 2	Variable set point with outdoor temperature compensation
Level 3	Variable set point with load dependent compensation. A control loop enables to control the supply air temperature. The setpoint is defined as a function of the loads in the room

Table 30: V-3: Free cooling with mechanical ventilation system [16]

Level 0	No automatic control
Level 1	Night cooling
Level 2	Free cooling: air flows modulated during all periods of time to minimize the amount of mechanical cooling
Level 3	H,x- directed control: The amount of outside air and recirculation air are modulated during all periods of time to minimize the amount of mechanical cooling. Calculation is performed on the basis of temperatures and humidity (enthalpy).

Table 31: V-6: Reporting information regarding IAQ [16]

Level 0	None
Level 1	Air quality sensors (e.g. CO2) and real time autonomous monitoring
Level 2	Real time monitoring & historical information of IAQ available to occupants
Level 3	Real time monitoring & historical information of IAQ available to occupants + warning on maintenance needs or occupant actions (e.g. window opening)

3.3.5 Lighting Tables

Tables 32 and 33 below show the individual SRI functionality levels for each of the smart ready services within the lighting domain. The specific services relevant to the lighting domain can be found in the titles of each of the following Tables 32 and 33. These services outline the detection of occupancy of a space and daylight levels at a given time of day.

Table 32: L-1a: Occupancy control for indoor lighting [16]

Level 0	Manual on/off switch
Level 1	Manual on/off switch + additional sweeping extinction signal
Level 2	Automatic detection (auto on / dimmed or auto off)
Level 3	Automatic detection (manual on / dimmed or auto off)

Table 33: L-2: Control artificial lighting power based on daylight levels [16]

Level 0	Manual (central)
Level 1	Manual (per room / zone)
Level 2	Automatic switching
Level 3	Automatic dimming
Level 4	Automatic dimming including scene-based light control (during time intervals, dynamic and adapted lighting scenes are set, for example, in terms of illuminance level, different correlated color temperature (CCT) and the possibility to change the light distribution within the space according to e. g. design, human needs, visual tasks)

3.4 Relevance to Study

Each of these levels from each indicated smart ready service, typically excluding the lowest Level 0 represent a way that a building's systems can use significantly less energy. If a building demonstrates a level less than the maximum within any service present, the higher services represent an apparent, tangible goal to strive towards as a direct means of lowering energy use.

4 Building Automation and Control Systems

While the SRI determines a score associated with the automated functions and the smartness of a building, the Building Automation and Control Systems (BACS) alone describes technology used to achieve these smart functions discussed [4]. This concept was introduced as the need for more sustainable practices in the building space arose. The idea of instituting automated capabilities to the systems of the building most responsible for energy consumption had the potential to make a difference even in the most primitive stages. The concept of BACS does not necessarily encompass the concept of smartness as it is know understood. For example, implementing heating or lighting systems with a timer function, a system that has existed for a significant period of time, in the context of an office building that is only used eight hours a day is considered automated.

4.1 Standard UNI EN ISO 52120-1:2022

As mentioned above in previous sections, the SRI is measured on a numerical scale, while the BACS can be measured on an alphabetical scale of A-D. This scale was established by Standard UNI EN ISO 52120-1:2022, where ISO is shorthand for International Organization for Standardization that is responsible for global standards regarding everything from safety of consumer goods to sustainability practices [17][18]. UNI and EN represent the subsections of Italian and European standards, respectively. This standard serves to provide a general way of measuring or at least representing the ability and the performance of the automated technology present in a building, the BACS. A table detailing the meanings of these levels is shown below.

Table 34: Descriptions of Each BACS Class Functionality [19]

BACS Class	Description
A	High Performance Building Automation and Control
B	Advanced Performance Building Automation and Control
C	Standard Performance Building Automation and Control
D	Poor Performance Building Automation and Control

This standard and the applied scale provide context to the capabilities of smart functions, and a direct means of lowering energy consumption.

4.2 Factor-Based Method for Assessing Energy Reduction Potential

One of the main objectives of the BACS is to reduce energy consumption. One way that that is quantified is through an established “Factor-Based Method”. This applies a value ranging from 0-2 for every possible domain, BACS class, and building type. This value is then used to calculate the possibility for energy reduction if changes are made to move from one BACS class to the next, within each domain [20]. This was ultimately developed to provide some context to the meaning of the alphabetical scale applied to the BACS class. What does a specific class mean and what are the implications of making meaningful changes to move to the class up or down a level? It can be used with an input of the energy consumption from any given time period; however, for the scope of this study, detailed below in Section 7, the value for the annual energy consumption of a given year will be used. The equation for this calculation is detailed below [21].

$$E_f = E_i \frac{f_f}{f_i} \tag{1}$$

This equation can be further modified to look like the equation below [21].

$$E_i - E_f = E_i(\frac{f_i - f_f}{f_i}) = E_i(1 - \frac{f_f}{f_i}) \tag{2}$$

In Equation 2 above E_i is the current energy consumption, E_f is the resultant energy consumption moving from one BACS class to another, f_i is the BACS factor associated with the current BACS class, and f_f is the BACS factor associated with the new desired BACS class. Additionally, $(1 - \frac{f_f}{f_i})$ alone is the percent by which the energy would potentially decrease.

The calculation of both the energy saving potential of the BACS class and the SRI value take into consideration the purpose of the building analyzed for similar reasons. For example, a hospital and an office building with the same smartness may have different SRI values. A hospital may have a larger need for significant ventilation for sanitary reasons, while an office building may have a larger need for heating and cooling capacity for occupant comfort. Along the same lines, the BACS factors reflect the varied needs of different spaces by the difference in potential for energy saving moving from one class to another across different domains. Tables 35-39 below show the BACS factors for the different types of buildings considered. Table 35 below shows the BACS factors for a residential building.

Table 35: Residential Building BACS Factors [21]

Domain	**D**	**C**	**B**	**A**
Heating	1.1	1	0.88	0.81
Cooling	1.11	1	0.9	0.8
Domestic Hot Water	1.1	1	0.88	0.81
Ventilation	1.15	1	0.85	0.72
Lighting	1.1	1	0.85	0.72

Table 36 below shows the BACS Factors for an office building

Table 36: Office Building BACS Factors [21]

Domain	**D**	**C**	**B**	**A**
Heating	1.504	1	0.79	0.7
Cooling	1.11	1	0.9	0.8
Domestic Hot Water	1.57	1	0.8	0.57
Ventilation	1.15	1	0.85	0.72
Lighting	1.1	1	0.85	0.72

Table 37 below shows the BACS Factors for an educational building

Table 37: Educational Building BACS Factors [21]

Domain	**D**	**C**	**B**	**A**
Heating	1.2	1	0.88	0.8
Cooling	1.11	1	0.9	0.8
Domestic Hot Water	1.502	1	0.87	0.64
Ventilation	1.12	1	0.88	0.74
Lighting	1.1	1	1	0.76

Table 38 below shows the BACS Factors for a healthcare building

Table 38: Healthcare Building BACS Factors [21]

Domain	**D**	**C**	**B**	**A**
Heating	1.501	1	0.91	0.86
Cooling	1.11	1	0.9	0.8
Domestic Hot Water	1.502	1	0.94	0.64
Ventilation	1.1	1	0.98	0.96
Lighting	1.1	1	1	1

Table 39 below shows the BACS Factors for a building that falls outside the previously mentioned categories.

Table 39: Other Building Types BACS Factors [21]

Domain	D	C	B	A
Heating	1.56	1	0.71	0.46
Cooling	1.11	1	0.9	0.8
Domestic Hot Water	1.59	1	0.71	0.55
Ventilation	1.13	1	0.95	0.91
Lighting	1.1	1	1	1

5 Method Explored by RINA Consulting Sustainability Team

While these two indices relating to the smartness and the BACS were developed separately and have different scales, their criteria are very closely related. The first five domains of the SRI are shared with the BACS, so the focus of the work completed as an intern at RINA was to develop an efficient way to link the two: to find a way to convert an SRI value, that has an accessible and already developed algorithm, to a corresponding BACS class.

There is significant overlap between the SRI services and the services outlined by UNI EN ISO 52120 that allow us to make comparisons between the two. This overlap also allows the use of SRI data to draw conclusions about the global BACS classes of each domain. This idea was initially explored by engineers at RINA using Microsoft Excel as the platform or this calculation that required manual input of the SRI functionality values for each relevant smart ready service.

The following is a detailed explanation of the process of the conversion of the SRI to the BACS class. As mentioned above, the individual BACS values of a domain are measured alphabetically using “A”, “B”, “C”, and “D”, while the SRI functionality level is indicated by a number from 0-4 that results in a percentage. The first goal of the excel sheet is to find the SRI criteria that corresponds appropriately to a BACS service and remove the SRI criteria that do not match. Table 40 below shows the services omitted from the study.

Table 40: smart ready services Omitted from Method

smart ready service	**Description of Service**
H-1c	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks
H-3	Report information regarding heating system performance
H-4	Flexibility and grid interaction
DHW-2b	Sequencing in case of different DHW generators
DHW-3	Report information regarding domestic hot water performance
C-3	Report information regarding cooling system performance
C-4	Flexibility and grid interaction
V-6	Reporting information regarding IAQ

Because the SRI criteria may have Level 0-Level 2, Level 0-Level 3, or Level 0-Level 4 (3, 4, and 5 total levels respectively) it is not quite as simple as converting it to class A through D. As will be shown below when there are 4 possible letters to assign to the BACS class and 3, 4, or 5 possible levels to be assigned to the SRI, it is impossible to simply correspond "Level 1" to "C", "Level 2" to "B", etc. Uniformly, an SRI value of "Level 0" was assigned to a BACS class of "D" and the highest functionality level for a classification (Level 3, 4, or 5 depending on the service) was assigned to a BACS class of "A". For example, both smart ready services **V-3: Free cooling with mechanical ventilation system** and **L-1: Artificial Lighting Control** both only have 4 possible SRI functionality levels. However, for smart ready service **V-3** the BACS classes assigned to Levels 0, 1, 2, and 3, respectively are D, C, B, A, while the BACS classes assigned to the same levels for smart ready service **L-1** are D, B, A, A. This was decided because the criteria for Levels 2 and 3 for **L-1** were deemed the fitting for the criteria necessary for an assigned BACS class of "A". Tables 41-65 below show the SRI smart ready service and its corresponding, or rather most similar, BACS service along with the appropriate letter assigned to each level in the left and right columns, respectively.

5.1 SRI Levels of Heating Domain and Corresponding BACS Classes

Tables 41-47 below show each relevant smart ready service within the heating domain, the number of levels associated with each one, and the the corresponding BACS classes.

Table 41: SRI H-1a and Corresponding BACS [22]

Heat emission control	**Emission control**
Level 0	D
Level 1	D
Level 2	C
Level 3	A
Level 4	A

Table 42: SRI H-1b Levels and Corresponding BACS Classes [22]

Emission control for TABS (heating mode	**Emission control for TABS**
Level 0	D
Level 1	C
Level 2	B
Level 3	A

Table 43: SRI H-1d Levels and Corresponding BACS Classes [22]

Control of distribution pumps in networks	**Control of distribution pumps in networks**
Level 0	D
Level 1	C
Level 2	B
Level 3	A
Level 4	A

Table 44: SRI H-1f Levels and Corresponding BACS Classes [22]

Thermal Energy Storage (TES) for building heating (excluding TABS)	**Control of thermal energy storage operation**
Level 0	D
Level 1	B
Level 2	A
Level 3	A

Table 45: SRI H-2a Levels and Corresponding BACS Classes [22]

Heat generator control (all except heat pumps)	**Heat generator control (combustion and district heating)**
Level 0	D
Level 1	C
Level 2	A

Table 46: SRI H-2b Levels and Corresponding BACS Classes [22]

Heat generator control (for heat pumps)	**Heat generation control (heat pumps)**
Level 0	D
Level 1	C
Level 2	A
Level 3	A

Table 47: SRI H-2d Levels and Corresponding BACS Classes [22]

Sequencing in case of different heat generators	**Sequencing of different heat generators**
Level 0	D
Level 1	C
Level 2	B
Level 3	A
Level 4	A

5.2 SRI Levels of Domestic Hot Water Domain and Corresponding BACS Classes

Tables 48-50 below show each relevant smart ready service within the domestic hot water domain, the number of levels associated with each one, and the the corresponding BACS classes.

Table 48: SRI DHW-1a Levels and Corresponding BACS Classes [22]

Control of DHW storage charging (with direct electric heating or integrated HP)	**Control of DHW storage charging (with direct electric heating or integrated HP)**
Level 0	D
Level 1	C
Level 2	B
Level 3	A
Level 4	A

Table 49: SRI DHW-1b Levels and Corresponding BACS Classes [22]

Control of DHW storage charging (using hot water generation)	**Control of DHW storage charging (using hot water generation)**
Level 0	D
Level 1	C
Level 2	A

Table 50: SRI DHW-1d Levels and Corresponding BACS Classes [22]

Control of DHW storage charging (with solar collector and supplementary heat generation)	**Control of DHW storage charging (with solar collector and supplementary heat generation)**
Level 0	D
Level 1	C
Level 2	A

5.3 SRI Levels of Cooling Domain and Corresponding BACS Classes

Tables 51-58 below show each relevant smart ready service within the cooling domain, the number of levels associated with each one, and the the corresponding BACS classes.

Table 51: SRI C-1a Levels and Corresponding BACS Classes [22]

Cooling emission control	**Emission control**
Level 0	D
Level 1	D
Level 2	C
Level 3	A
Level 4	A

Table 52: SRI C-1b Levels and Corresponding BACS Classes [22]

Emission control for TABS (cooling mode)	**Emission control for TABS**
Level 0	D
Level 1	C
Level 2	B
Level 3	A

Table 53: SRI C-1c Levels and Corresponding BACS Classes [22]

Control of distribution network chilled water temperature (supply or return)	**Control of distribution network chilled water temperature**
Level 0	D
Level 1	C
Level 2	A

Table 54: SRI C-1d Levels and Corresponding BACS Classes [22]

Control of distribution pumps in networks	**Control of distribution pumps in networks**
Level 0	D
Level 1	C
Level 2	B
Level 3	A
Level 4	A

Table 55: SRI C-1f Levels and Corresponding BACS Classes [22]

Interlock: avoiding simultaneous heating and cooling in the same room	**Interlock between heating and cooling control of emission and/or distribution**
Level 0	D
Level 1	B
Level 2	A

Table 56: SRI C-1g Levels and Corresponding BACS Classes [22]

Control of Thermal Energy Storage (TES) operation	**Control of TES charging**
Level 0	D
Level 1	C
Level 2	A
Level 3	A

Table 57: SRI C-2a Levels and Corresponding BACS Classes [22]

Generator control for cooling	**Generator control for cooling**
Level 0	D
Level 1	C
Level 2	A
Level 3	A

Table 58: SRI C-2b Levels and Corresponding BACS Classes [22]

Sequencing of different cooling generators	**Sequencing of different cooling generators**
Level 0	D
Level 1	C
Level 2	B
Level 3	A
Level 4	A

5.4 SRI Levels of Ventilation Domain and Corresponding BACS Classes

Tables 59-63 below show each relevant smart ready service within the ventilation domain, the number of levels associated with each one, and the the corresponding BACS classes.

Table 59: SRI V-1a Levels and Corresponding BACS Classes [22]

Supply air flow control at the room level)	**Supply of air flow control at the room level)**
Level 0	D
Level 1	B
Level 2	B
Level 3	A
Level 4	A

Table 60: SRI V-1c Levels and Corresponding BACS Classes [22]

Air flow or pressure control at the air handler level)	**Air flow or pressure control at the air handler level)**
Level 0	D
Level 1	C
Level 2	B
Level 3	A
Level 4	A

Table 61: SRI V-2c Levels and Corresponding BACS Classes [22]

Heat recovery control: prevention of overheating	Heat recovery control: prevention of overheating
Level 0	D
Level 1	A
Level 2	A

Table 62: SRI V-2d Levels and Corresponding BACS Classes [22]

Supply air temperature control at the air handling unit level	Supply air temperature control at the air handling unit level
Level 0	D
Level 1	C
Level 2	B
Level 3	A

Table 63: SRI V-3 Levels and Corresponding BACS Classes [22]

Free cooling with mechanical ventilation system	Free cooling with mechanical ventilation system
Level 0	D
Level 1	C
Level 2	B
Level 3	A

5.5 SRI Levels of Lighting Domain and Corresponding BACS Classes

Tables 64-65 below show each relevant smart ready service within the lighting domain, the number of levels associated with each one, and the the corresponding BACS classes.

Table 64: SRI L-1a Levels and Corresponding BACS Classes [22]

Artificial lighting control	**Occupancy control**
Level 0	D
Level 1	B
Level 2	A
Level 3	A

Table 65: SRI L-2 Levels and Corresponding BACS Classes [22]

Control artificial lighting power based on daylight levels	**Light level/daylight control**
Level 0	D
Level 1	B
Level 2	B
Level 3	A
Level 4	A

Using this side-by-side definition, each BACS class for each criterion can be assigned based simply on the level indicated by the SRI definitions. The difference between the calculation of the overall SRI percentage and the overall BACS class is that the former is based on an algorithm that factors in the level of each smart ready service with the appropriate domain weightings, where the latter is based on the lowest performing value alone. For example, if given an office building located in southern Europe that exhibits **lighting automatic detection (manual on / dimmed or auto off) for occupancy control of building lighting** per smart ready service **L-1a** and **manual (central) control of artificial lighting power based on daylight levels** per smart ready service **L-2**, a Level 3 and Level 0, respectively, using the SRI calculation spreadsheet, this would result in an overall SRI score for lighting of 36%. However, this same basis would yield a BACS class of A and D, respectively, resulting in an overall BACS class for lighting of D, regardless of the high performing A BACS class rating for one of the smart ready services.

6 Developed App for Calculation of BACS Class and Potential Energy Reduction

Though this method had begun to be examined by engineers at RINA, it still required manual input and was missing several services. The scope of the research conducted at during this internship for the purpose of this thesis was to create a standalone app in MATLAB App Designer based on the established algorithm to streamline this process and to make the information regarding the building smartness, BACS class, and potential for energy saving readily available to users of the SRI spreadsheet. The App Designer function, standard within MATLAB, was chosen as the desired platform partly because of its capability to read and pull data from an excel spreadsheet without importing the entire dataset. In this case the spreadsheet used for the SRI calculation is enormous and would dramatically slow operations if it was necessary to import and read 100% of the information within it. The following sections detail how MATLAB App Designer is used both in general and also within the scope of this research.

6.1 Introduction of MATLAB App Designer

MATLAB App Designer is a built-in function within the MATLAB software that creates a stand-alone app that allows a user to take advantage of the functionality of MATLAB without the need for a license that is only open-access to people affiliated with certain organizations. MATLAB App Designer has nearly identical notation to standard MATLAB, but the code and the functions are not automatically executed when the app is run. App Designer employs buttons, slider bars, drop-down menus, and other interactive components to create functionality and a comprehensive user interface for the final product. This allows for code to be performed in increments and can be altered without rerunning the code from the beginning. A detailed description including diagrams will be included in the following section.

The general formula for the app that was created is as follows. The first step is to immediately read the SRI spreadsheet and populate a User Interface (UI) Table with the 25 relevant smart ready services and their values ranging from 0-4 alongside its accompanying description using a button labeled *Import*. Once the values are stored in a data table, the corresponding alphabetical BACS values are calculated based on the scale established in Tables 41-65 and stored in the same UI table. An additional UI Table that relies on user input of the energy use of a given period is added. This information is usually taken from existing data of energy use of a building during a given period and varies based on the project like the SRI inputs. This is used when calculating the energy saving potential using the BACS factors taken from Tables 35-39. A button labeled *Calculate* is added that when pressed, the global BACS class for each domain per the description in Section 5 is calculated and stored in a second table alongside the energy saving percentage and other relevant information to be described below. Next, the overall SRI values are taken from the excel file and used to replicate the bar graph generated within the excel file. It is placed next to a bar graph of the global BACS classes to show a side-by-side comparison and observe any possible trends.

The final part of the app is designed to generate a report in PDF format of the calculated data. This is done with a UI Table that allows for the addition of the user's name, a report title, and the date to a cover page. To accomplish this, a button labeled *Export* is included that when pressed, exports all the data, both input and calculated, in a PDF with accompanying descriptions. An example of this PDF based on a case study described in Section 7 is available in Appendix A. Figure 3 below shows the blank dashboard of the app to provide some context for the locations of the described buttons and UI tables.

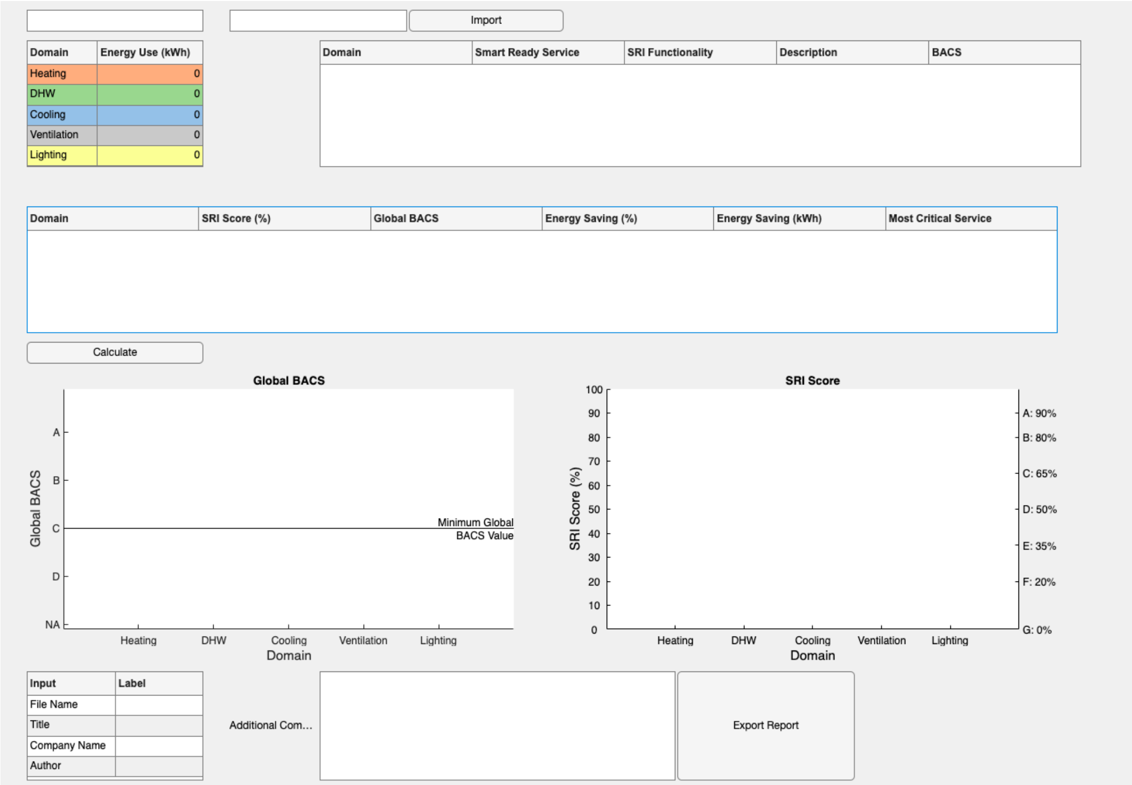


Figure 3: Screenshot of Dashboard for the Described App

6.2 Method Used to Develop App and Description of Script

The following section details the MATLAB script to show the exact process of the necessary calculations. To begin the process of using the app, two blank, editable components are added to the app's dashboard, shown above in Figure 3. One represents the file path of the SRI spreadsheet and the location of a resulting PDF report to be detailed further on in this section, and the other represents the corresponding file name of the spreadsheet. This also allows the app to be modular in the sense that it can be recycled for any project that makes use of the standard SRI spreadsheet without having to modify the code. Then a button labeled *Import* is pressed which activates the following code. A matrix that represents the order and possible values for the assigned BACS class for each criterion is initialized.

[D,D,C,A,A; %- H-1a

D,C,B,A,NA; %- H-1b

D,C,B,A,A; %- H-1d

D,C,A,NA,NA; %- H-1f

D,C,A,A,NA; %- H-2a

D,C,B,A,A; %- H-2b

D,B,A,A,NA; %- H-2d

D,C,A,NA,NA; %- DHW-1a

D,C,A,NA,NA; %- DHW-1b

D,C,A,NA,NA; %- DHW-1d

D,D,C,A,A; %- C-1a

D,C,B,A,NA; %- C-1b

D,C,A,NA,NA; %- C-1c

D,C,B,A,A; %- C-1d

D,B,A,NA,NA; %- C-1f

D,C,A,A,NA; %- C-1g

D,C,A,A,NA; %- C-2a

D,C,B,A,A; %- C-2b

D,B,B,A,A; %- V-1a

D,C,B,A,A; %- V-1c

D,A,A,NA,NA; %- V-2c

D,C,B,A,NA; %- V-2d

D,C,B,A,NA; %- V-3

D,B,A,A,NA; %- L-1a

D,B,B,A,A] %- L-2

This matrix is a reduced form of Tables 41 to 65 shown above creating a parallel between the SRI and the BACS value. In MATLAB notation, commas separate columns, while semicolons separate rows. As shown, there are some cells that have a value of "NA". This was included because, as shown above, the smart ready services do not have a uniform length, so a "filler" value was included to have a uniform matrix 25x5. This matrix's 25 rows represent each of the criteria to be assessed in the order shown in Tables 41-65. It proved to be more streamlined to combine the data for heating, cooling, domestic hot water, ventilation, and lighting into one matrix versus separating the data into five separate matrices.

The first issue that had to be overcome is that within the SRI calculation spreadsheet there is a specific column J dedicated to the SRI value 0-4, but its availability and its actual value that can be used for the purpose of BACS calculation relies on the adjacent columns E and F. Figure 4 below shows a screenshot of the SRI calculation spreadsheet of all the rows dedicated to the lighting domain with the relevant columns.

B	C	D	E	F	G	I	J
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is absent and not mandatory	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect maximum obtainable score when not present in building	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor
L-1a	Artificial lighting control	Occupancy control for indoor lighting	1	1	1	1	
L-2	Control artificial lighting power based on daylight levels	Control artificial lighting power based on daylight levels	1	1	1	1	

Figure 4: Screenshot of the Lighting Domain Rows Within the SRI Excel Spreadsheet

The values in column J are the actual SRI functionality values: the number associated with the relevant level. However, its availability and its inclusion in the SRI calculation of this document as well as the BACS calculation of the designed app rely on columns E and F. Column E stipulates if the designated service is to be included or not and is populated by a 1 or 0, respectively. Column F stipulates if the overall domain is present, if it is absent but mandatory, or if it is absent and not mandatory and is populated by a 1, 2, or 0, respectively. For a service to be included in the calculation or, regarding the app, for the Column J value to be read, both columns E and F need a value of 1. The following figures are the result of three different scenarios that might occur, where the service would not be included using the first service of the heating domain as an example. Figure 5 below depicts the scenario when the service is to be included in the selected method per column E and the heating domain is absent but mandatory.

B	C	D	E	F	G	I	J
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is absent and not mandatory	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect maximum obtainable score when not present in building	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor
H-1a	Heat control - demand side	Heat emission control	1	2	0		

Figure 5: Screenshot of a Singular Smart Ready Service within the Excel Spreadsheet when Column F is Assigned a Value of ”2”

Figure 6 below depicts the scenario when the service is to be included in the selected method per column E and the heating domain is absent but not mandatory.

B	C	D	E	F	G	I	J
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is absent and not mandatory	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect maximum obtainable score when not present in building	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor
H-1a	Heat control - demand side	Heat emission control	1	0	0		

Figure 6: Screenshot of a Singular Smart Ready Service within the Excel Spreadsheet when Column F is Assigned a Value of ”0”

Figure 7 below depicts the scenario when the service is not to be included. Even if column F has the necessary value of 1, the calculation will still not accept an input from column J.

B	C	D	E	F	G	I	J
Code	Service group	Smart ready service	Service included in the selected method (A/B/custom): 0 - not included, 1 - included	1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is absent and not mandatory	TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect maximum obtainable score when not present in building	Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable	Main functionality level as inspected by SRI assessor
H-1a	Heat control - demand side	Heat emission control	0	1	0		

Figure 7: Screenshot of a Singular Smart Ready Service within the Excel Spreadsheet when Column F is Assigned a Value of ”1” but Column E is Assigned a Value of ”0”

As apparent, when columns E and F don’t both have the necessary values of 1 to include the smart ready service, the cell corresponding to column J is filled in with a grey rectangle. This is the result when the service is not to be included based on the criteria described above. However, although the cell is filled in with this grey rectangle, the cell may still have a value. The design of the excel spreadsheet is intricate enough that it knows to omit any value that may be present in column J if it’s covered with this rectangle, but the value may still be present. So, if a service is being reassessed, or the spreadsheet is being recycled for a new project, the values in columns E and F may be changed without the need to change the value in column J. This is perfectly acceptable for the purpose of the functionality of the excel sheet but may cause problems in the development of the MATLAB algorithm if not considered. This is all to say that in an ideal situation, the MATLAB code would simply read column J and pull the necessary data; however, it needs to extract both column E and F and compare values. Without this consideration, a value for the SRI would be considered even without the necessary values of 1 in both columns E and F.

If columns E and F have the necessary values of 1, the corresponding value in column J is stored in an array, but if not, a value of *NaN*, MATLAB's notation for *Not a Number* is stored in this array in place of a number. As mentioned above in Section 5, not all the classes used for the SRI calculation are considered for the BACS class calculation. Because of this, an array of the necessary indices pulls only the relevant smart ready services and corresponding values from this column J. Assuming no changes to the rows and columns in the excel file are made, this array of 25 values should correspond perfectly to the matrix replicated above.

Once these values are established, a UI table is populated with the 25 smart ready services considered in the study, the SRI level, description of the smart ready service , and the letters corresponding to the BACS values of Tables 41-65. Figure 8 below shows the a screenshot of this UI table when no data is imported. The ”NaN” an ”NA” columns are filler values and would be replaced by the appropriate values when used with actual data.

Domain	Smart Ready Service	SRI Functionality	Description	BACS
Heating	Heat emission control	NaN		NA
Heating	Emission control for TABS (heating mode)	NaN		NA
Heating	Control of distribution fluid temperature (supply or ret…	NaN		NA
Heating	Thermal Energy Storage (TES) for building heating (…	NaN		NA
Heating	Heat generator control (all except heat pumps)	NaN		NA
Heating	Heat generator control (for heat pumps)	NaN		NA
Heating	Sequencing in case of different heat generators	NaN		NA
DHW	Control of DHW storage charging (with direct electric…	NaN		NA
DHW	Control of DHW storage charging (using hot water g…	NaN		NA
DHW	Control of DHW storage charging (with solar collecto…	NaN		NA
Cooling	Cooling emission control	NaN		NA
Cooling	Emission control for TABS (cooling mode)	NaN		NA
Cooling	Control of distribution network chilled water temperat…	NaN		NA
Cooling	Control of distribution pumps in networks	NaN		NA
Cooling	Interlock: avoiding simultaneous heating and cooling…	NaN		NA
Cooling	Control of Thermal Energy Storage (TES) operation	NaN		NA
Cooling	Generator control for cooling	NaN		NA
Cooling	Sequencing of different cooling generators	NaN		NA
Ventilation	Supply air flow control at the room level	NaN		NA
Ventilation	Air flow or pressure control at the air handler level	NaN		NA
Ventilation	Heat recovery control: prevention of overheating	NaN		NA
Ventilation	Supply air temperature control at the air handling uni…	NaN		NA
Ventilation	Free cooling with mechanical ventilation system	NaN		NA
Lighting	Occupancy control for indoor lighting	NaN		NA
Lighting	Control artificial lighting power based on daylight levels	NaN		NA

Figure 8: Screenshot of Template of UI Table of Imported Data

This is an area where the user may induce an error. The path name and the file name have to be exactly correct, or the data will not populate the table and an error will appear. However, this can be changed without need to rerun the app from the beginning. However, if this occurs, the field can be edited, and the *Import* button can be pressed again.

Next to this UI table shown in Figure 8 is another with two columns, one showing the domain and the other showing energy use in kWh over a predetermined period of time. The latter column is editable. A screenshot of a blank example of which is shown below in Figure 9.

Domain	Energy Use (kWh)
Heating	0
DHW	0
Cooling	0
Ventilation	0
Lighting	0

Figure 9: Screenshot of Energy Use UI Table

The values in the Energy Use (kWh) column are populated manually by the user and will be used to calculate the energy saving potential using the BACS factor method. Zero values are shown here for each domain as filler values.

Once the tables represented in Figures 8 and 9 are populated, the *Calculate* button is pressed. This initiates the actual calculations of the global BACS class and the energy saving potentials for each domain. The global BACS class is calculated in the MATLAB code similarly to the method described above in Section 5; however, MATLAB performs the operation in a much more streamlined way. This is done by iterating through each domain and creating individual arrays of the BACS classes within a domain from the final column of the input table representing the individual BACS classes shown in Figure 8. It then sorts each array in alphabetical order from A-D, ignoring the values of "NA" that result from that smart ready service not being included in the study determined by the stipulations described by Figures 5-7. It then takes the last value in the sorted list representing the worst performing BACS class and assigns that value to the global BACS. Given the potential scenario where each value in within the domain was neglected or not included in the study resulting in an array full of "NA" values the app assigns the global BACS to "NA" for the domain and the calculations for the remaining results are not performed.

To perform the operations for the following the energy saving potential, the appropriate values from Tables 35-39 need to be considered. A string variable is declared that pulls the building type directly from the SRI spreadsheet in the section that details the building information. Any building will either be residential or non-residential. However, there are several categories within each option. For residential buildings, the options within the spreadshet are *residential – single-family home*, *residential – small multi-family home*, *residential – large multi-family home*, and *residential – other*. The options for non-residential buildings are *non-residential – office*, *non-residential – educational*, *non-residential – healthcare*, and *non-residential – other*. As shown above, all residential homes, regardless of size or number of families occupying the space, use the same BACS factors, whereas each of the four classifications for non-residential buildings require their own set of BACS factors. There is one drop-down menu for building type (residential vs. non-residential) then another for building usage, which specifies the subtype. The script then reads the type and usage and declares a matrix based on these Tables 35-39, an image of which is depicted below in Figure 10.

```
if res
            BACS_facs=[1.1,1,.88,.81;
                       1.11,1,.9,.8;
                       1.57,1,.8,.57;
                       1.15,1,.86,.72;
                       1.1,1,.85,.72];
        elseif strcmp(non,'non-residential - office')
            BACS_facs=[1.44,1,.79,.7;
                       1.11,1,.9,.8;
                       1.57,1,.8,.57;
                       1.15,1,.86,.72;
                       1.1,1,.85,.72];
        elseif strcmp(non,'non-residential - educational')
            BACS_facs=[1.2,1,.88,.8;
                       1.11,1,.9,.8;
                       1.32,1,.94,.64;
                       1.12,1,.87,.74;
                       1.1,1,.88,.76];
        elseif strcmp(non,'non-residential - healthcare')
            BACS_facs=[1.31,1,.91,.86;
                       1.11,1,.9,.8;
                       1.32,1,.94,.64;
                       1.1,1,.98,.96;
                       1.2,1,1,1];
        elseif strcmp(non,'non-residential - other')
            BACS_facs=[1.56,1,.71,.46;
                       1.11,1,.9,.8;
                       1.59,1,.71,.55;
                       1.13,1,.95,.91;
                       1.1,1,1,1];
        end
```

Figure 10: Relevant Lines of Code Corresponding to the BACS Factors

The line “if res” reads if the building type is residential which sets the BACS factors to the corresponding values for residential buildings. The following lines that begin with “elseif” are executed if the type is non-residential (specified by the variable “non”) and iterates through each type of non-residential until the correct type is found. Once the correct matrix is declared, the energy saving can be calculated. The energy saving percent is then performed based on Equation (2) and replicated below.

$$\% = 1 - \frac{f_f}{f_i}$$

In this case, f_i is the BACS factor value corresponding to the appropriate domain, based on the row number, and the BACS class calculated from the domain’s SRI value, and f_f is the BACS factor value of the same domain in the next BACS class. This formula doesn’t have to be used for consecutive BACS classes, but for simplicity’s sake that’s the method that this app used. Of course, if the BACS class is already assigned the highest value of “A”, this calculation is neglected.

This percentage is a universal value regardless of the energy input. However, as mentioned above and shown in Figure 9, the user provides an experimental energy input. This value is pulled from the table and multiplied by the calculated percentage. This provides the potential for energy saving in units of energy. The table is labeled *kWh* because this app was designed with the units associated with annual energy use within Italy in mind which is usually represented by *kWh*. Despite this, because the percentage and the factors are unitless and universal, the input energy values can be represented by units used for smaller quantities such as Joules, for example, or even imperial units, when relevant, such as BTU. This calculated data culminates in another UI table, a screenshot of an empty example of which is shown below in Figure 11.

Domain	SRI Score (%)	Global BACS	Energy Saving (%)	Energy Saving (kWh)	Most Critical Service
Heating	NaN	NA	0	0	
DHW	NaN	NA	0	0	
Cooling	NaN	NA	0	0	
Ventilation	NaN	NA	0	0	
Lighting	NaN	NA	0	0	

Figure 11: Screenshot of Template of UI Table Displaying Results of Study

The table is populated with columns corresponding to the Domain, the SRI Score (%) pulled directly from the input excel file, the calculated Global BACS Class, the energy saving potential percentage, the energy saving potential in units of energy, and finally a column labeled "Most Critical Service". This final column takes each smart ready service within a domain that shares a BACS class with the global BACS class and fills the cell with a list of these services. This is ultimately because the global BACS class is based on the singular weakest service, so if the weakest services are addressed, the class would automatically improve.

The next steps performed in the app aim to display the relevant information visually. The best means of completing this is by a bar graph showing the global BACS values for each domain. The template for this is shown above in Figure 3 and replicated below in Figure 12.

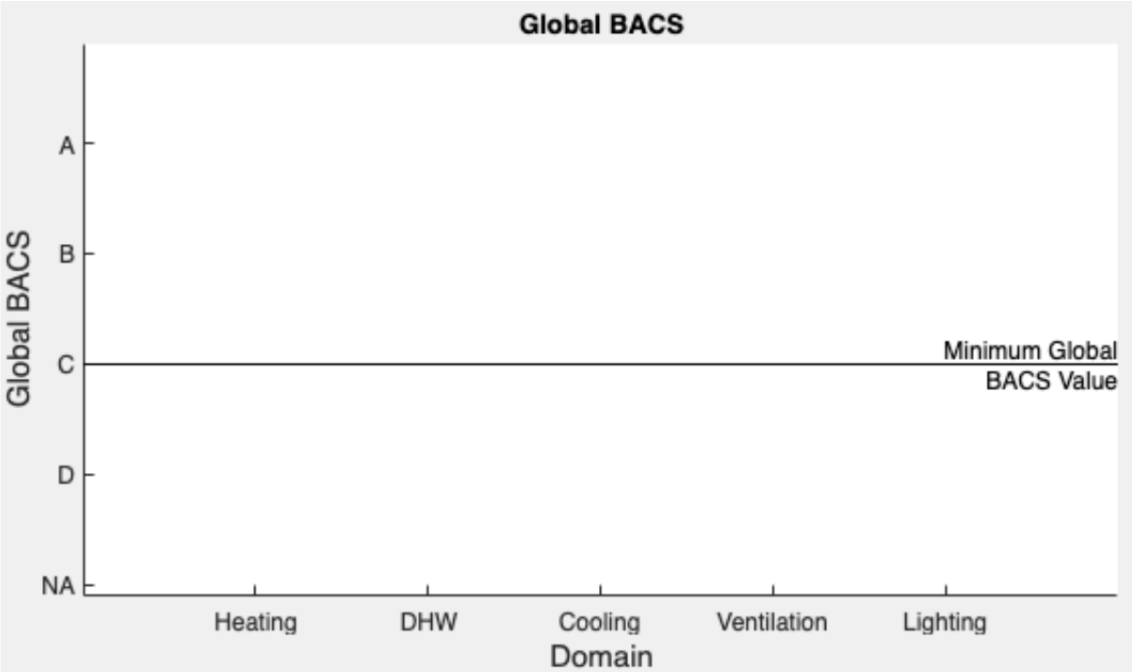


Figure 12: Template for the Bar Graph of the Globabl BACS Classes for Each Domain

When the app is run, the plot is populated with bars corresponding to the global BACS values represented in the y-axis. As part of the final results of the SRI spreadsheet, the file displays the SRI percentage for each domain in a bar graph. A template of which is replicated below in Figure 13.

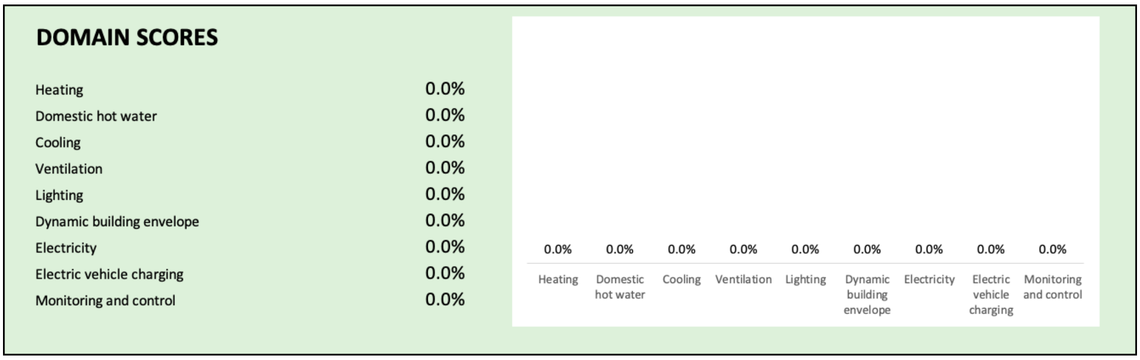


Figure 13: Template for the Bar Graph of the SRI Values for Each Domain from Excel

As mentioned above, the domains dynamic building envelope, electricity, electric vehicle charging, and monitoring and control domains are not included in the scope of the study, but in the context of the excel sheet, they are shown next to the five relevant domains. For a visual comparison, this information is read by the MATLAB app and shown in a similar bar graph. The template for this is shown above in Figure 3 and replicated below in Figure 14.

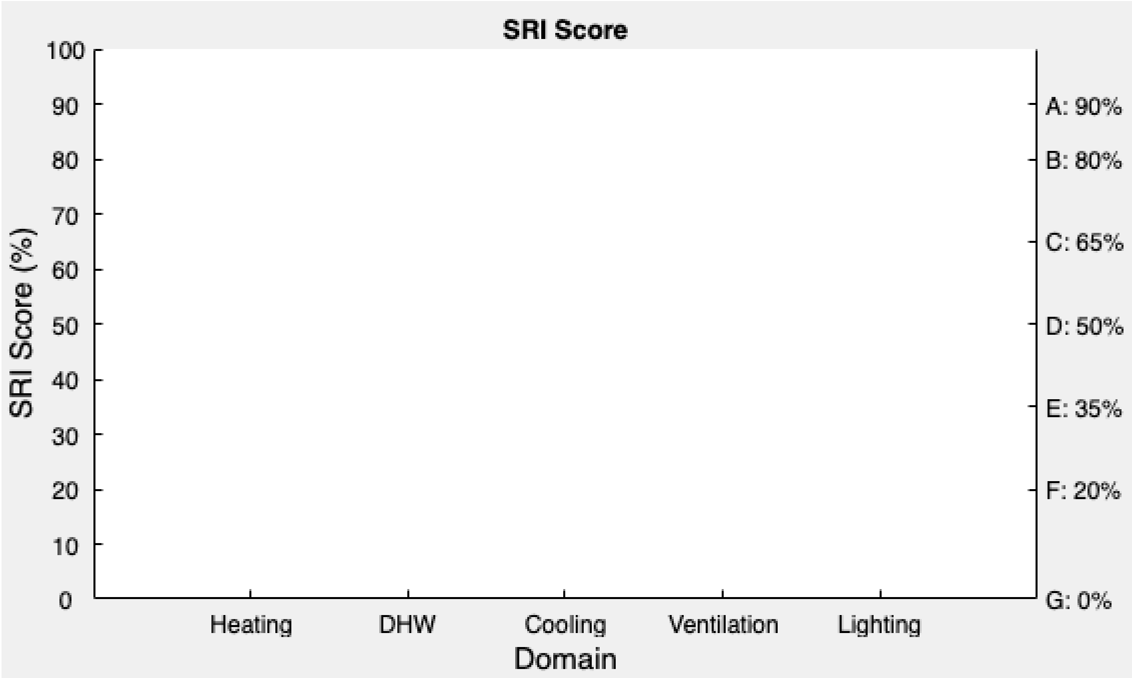


Figure 14: Template for the Bar Graph of the SRI Values for Each Domain from MATLAB

On the left side y-axis shows the SRI score in 10% increments for visualization, while the right side y-axis shows the functionality levels measured by a corresponding letter. Throughout this thesis, the scale of the SRI is distinguished from that of the BACS by its use of a percentage vs. letters. Without contradicting this established distinction, there is an associated letter value for the percentages shown on the right side y-axis that is mostly used for practical purposes. That is to say that this letter value is mostly used in real circumstances to provide a bit of context and a scale that makes sense to a consumer. These tables will be replicated with actual values and graphical elements below in Section 7 that discusses the case study.

To make this information accessible outside the context of MATLAB, the final component of this app is an option to export the necessary information in a concise PDF format. This occurs when a final button labeled *Export Report* is pressed. To accomplish this export procedure, the *Report* function is utilized. This function in MATLAB allows for graphics, tables, images, text, etc. to be used to create an exported document, in this case with a file type of PDF. A last UI table is included in the app which contains rows corresponding to a file name, a report title, the relevant organization's name, and the author or user's name. Additionally, a blank text box that allows for additional and optional comments from the app user is included next to this UI table, both of which can be seen in Figure 3. This section will most likely be used to discuss the results or make suggestions for changes to the building based on the results table that specifies problem areas. Additionally, if the building does not meet the minimum BACS class, changes, by definition of the minimum BACS class, need to be made. This optional text will be included at the end of the exported report. Each of these rows are optional, meaning that the code still functions without this input information, and the report is still generated. In this case that it is generated without this input information, an untitled document is created, and the title page will be blank.

Because the export document function is strictly for image and text elements, the data or contents couldn't be taken directly from the code. More specifically, the graphs and the UI tables presented in the app are visual representations of the lines of code, but they are not themselves image and text elements. To get around this, the *exportgraphics* function is first used. This exports the graphs as images to the specified folder. This allows the app to then pull this content into the report and allows the individual images to be accessible to the user. Similarly, the *Report* function cannot accept the UI tables simply as they are within the app. The information from the tables is used to create a standard table which differs from a UI table because it has no interactive capabilities. Then from an aesthetics standpoint, the column width, row height, style, font, font size, etc. need to be modified to display the information clearly and concisely. An example of what this finished report will be included in Appendix A based on the case study described in Section 7.

The app also allows for errors to be made and corrected without the need to rerun the program. If there are multiple projects to be analyzed, the filename input can be changed and the buttons repressed in the correct order of *Input*, *Calculate*, *Export Report*. Alternatively, if changes need to be made in the moment to the comments or the input information for the exported report, a new PDF can be generated that overwrites the previously generated file. If several copies need to be saved with different comments or different energy consumption values, the file path at the top of the app can be changed repeatedly and new reports can be generated and saved in each additional folder without the need to copy the file and duplicate it in the necessary folder. These are small, almost insignificant changes, but they speak to the usability of the program to streamline the generation of this information.

6.3 Potential Problems

As mentioned in the section above, the accuracy of the app relies on zero changes being made to the excel file. In the case that a necessary cell has been deleted or a shift has occurred, the app will not perform the calculations properly. However, this accidental modification would also directly affect the calculation of the SRI and could potentially be caught and remedied by the user assuming familiarity with the feasibility and the expected outcome of the resulting SRI.

7 Case Study

While testing the development of this MATLAB app, several hypothetical SRI excel spreadsheets were used. This is to say that the SRI spreadsheets from past projects that could be modified for the purposes of debugging and troubleshooting were primarily used. Once the app was perfected to the point that any general developed SRI spreadsheet could be input, it could be used in the case of a project that RINA had been asked to consult on. The selected project was renovation of the building headquarters of the Regional Council of Lazio in Rome, Italy and its current building systems. Figure 15 below shows an image of the building.

Figure 15: Regione Lazio Building [23]

The entirety of the complex is being considered for renovation in the hopes of creating a final product that will stand the test of time and consume considerably less energy than the current structure. When updating a building whose original systems are over fifty years old, changes to almost every aspect of the building need to be made. The addition of updated photovoltaic panels, the introduction of proper insulation, and the replacement of harmful materials, for example, are all to be considered. The role that the research described in this thesis plays is the examination of the smart systems put in place over the years. This section will examine the current state of smartness of the building, the corresponding BACS class based on the scale established by UNI ISO EN 52120, and suggestions for the building and buildings like it going forward.

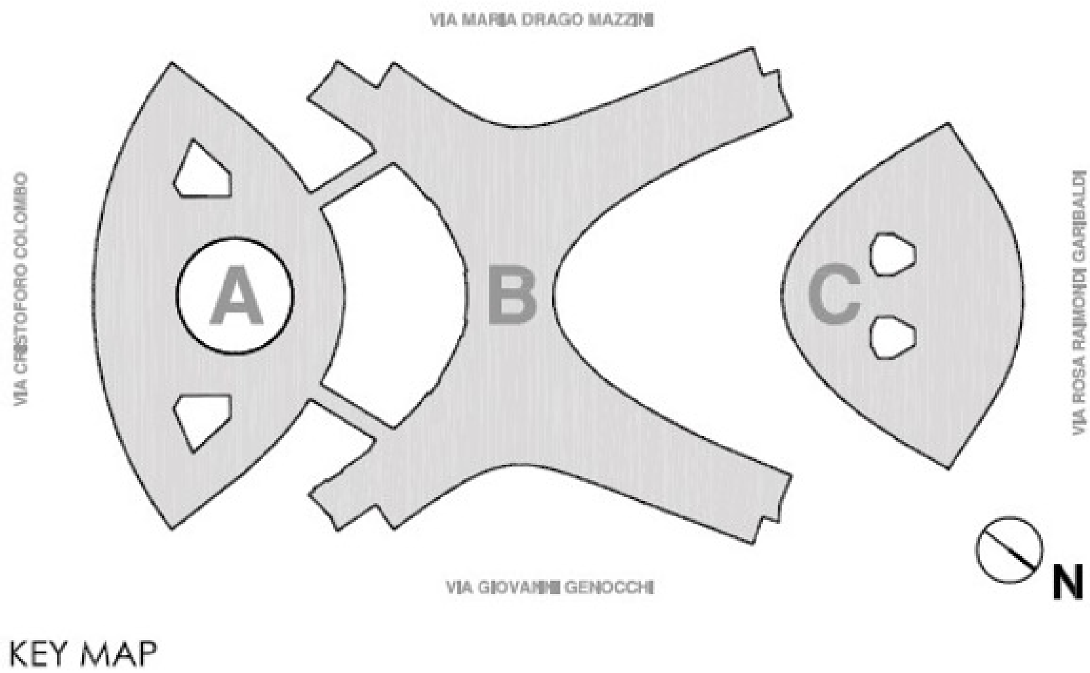


Figure 16: Site Map of The Enire Structure [23]

The entire structure is made up of three buildings, all of which are have concave or convex parabolic walls of windows. The part of the complex that this analysis will cover is Building C shown above in Figure 16. The mechanical systems of each of the buildings are independent, which allows them to be analyzed individually like this. The information needed to complete this study was found after carefully parsing through an extensive energy audit of the structures.

7.1 Process of Calculation of Building Smartness and Corresponding BACS Classes

To begin the process of determining the SRI score for the building, the information about the building regarding the general information, building type, location, etc. need to be input within the SRI spreadsheet.

GENERAL BUILDING INFORMATION

Building type	non-residential
Building usage	non-residential - office
Location	Italy
Climate zone:	*South Europe*
Total useful floor area of the building	> 25.000 m²
Year of construction	1960 - 1990
Building state	Original
Please provide a brief description of the building	
Address:	

Figure 17: General Building Information from the SRI Spreadsheet [16]

METHODOLOGY SELECTION

Preferred weightings	Default
Preferred services catalogue	B

Domains present

Are the following technical building systems present in your building?
If not, are they mandatory for new constructions in your country of residence?
1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is absent and not mandatory

Heating	1
Domestic hot water	1
Cooling	1
Ventilation	2
Lighting	1
Dynamic building envelope	0
Electricity	1
Electric vehicle charging	0
Monitoring and control	1

Figure 18: Methodology Selection from the SRI Spreadsheet [16]

The “Building type” and “Building usage” show “non-residential” and “non-residential - office”, respectively, which will be used not only to calculate the SRI value but will also be used to determine which table of BACS factors to use for the calculation of the energy saving potential. The rest of the user inputs—size, construction year, building state—will all affect the SRI value. This is done by referencing the Domain Weightings and the Impact Weightings defined in the “Weightings” tab of the excel spreadsheet. The ”Domains present” part of Figure 18 are the values to be used in Column F referenced above in Figures 5-7.

The following two tables are the single table representing the domain weightings based on the input building information split into two separate tables for clarity.

Table 66: First Four Columns of the Domain Weightings Table [16]

Domain	**Energy efficiency**	**Energy flexibility and storage**	**Comfort**	**Convenience**
Heating	0.3	0.42	0.16	0.1
Cooling	0.12	0.16	0.16	0.1
Domestic Hot Water	0.11	0.15	0.00	0.1
Ventilation	0.09	0.00	0.16	0.1
Lighting	0.12	0.00	0.16	0.1
Electricity	0.02	0.02	0.00	0.1
Dynamic building envelope	0.05	0.00	0.16	0.1
Electric vehicle charging	0.00	0.05	0.00	0.1
Monitoring and control	0.2	0.2	0.2	0.2
	1.00	1.00	1.00	1.00

Table 67: Last Three Columns of the Domain Weightings Table [16]

Domain	Health, well-being, and accessibility	Maintenance and fault prediction	Information to Occupants
Heating	0.2	0.36	0.11
Cooling	0.2	0.14	0.11
Domestic Hot Water	0.0	0.13	0.11
Ventilation	0.2	0.1	0.11
Lighting	0.00	0.00	0.00
Electricity	0.00	0.02	0.11
Dynamic building envelope	0.2	0.05	0.11
Electric vehicle charging	0.00	0.00	0.11
Monitoring and control	0.2	0.2	0.2
	1.00	1.00	1.00

These weightings generally show a heavier emphasis on heating and cooling and very little emphasis on domestic hot water, which makes sense for an office space. The following table represents the single Impact Weightings table based on the input building information split into two for clarity.

Table 68: First Four Columns of the Impact Weightings Table [16]

Energy Efficiency	Energy flexibility and storage	Comfort	Convenience
0.17	0.33	0.08	0.08

Table 69: Last Three Columns of the Impact Weightings Table [16]

Health, well-being, and accessibility	Maintenance and fault prediction	Information to occupants
0.08	0.17	0.08

As mentioned in Section 3, this weighting exists because different climates and kinds of buildings require different criteria. To establish the individual SRI levels for the following step, the existing reports and specs were used. The next part of the SRI spreadsheet to be filled in was the “Calculations” tab. This is where the data regarding the specific SRI levels for the smart ready services are indicated for SRI calculation.

The following tables have been generated using the data from the SRI spreadsheet. Several of the present columns, an example of which is shown above in Figure 4 have been omitted for clarity and conciseness. The column regarding the service group was taken out because it represents a subcategory within the domain and is not relevant to the scope of the study. The column labeled “TRIAGE: 1 - This service affects maximum obtainable score, even if service is not applicable in this building; 0 - This service does not affect maximum obtainable score when not present in building” because it a column with predetermined data that the user is not meant to modify and is therefore not especially important for the purposes of this section. The column labeled “Service applicable in your building? - to be assessed by the assessor: 1 - applicable; 0 - not applicable” was omitted because though it is a value determined by the user-defined input shown in Figures 5-7, the value of 1 is represented by a yellow background in the “Main functionality level” column, and a value of 0 is represented by a grey rectangle in the same column. The “Calculations” tab in excel spans another eleven columns which specify the definitions of the SRI levels and other irrelevant information. These were also omitted for clarity.

In addition to the omitted columns, several column headers have been modified for conciseness. The column in the tables below labeled ”Service Included” represents the column in the SRI spreadsheet labeled “Service included in the selected method (A/B/custom): 0 - not included, 1 – included”. This is the user defined column where either a value of 1 or 0 is input depending on whether the smart ready service is included in the study, originally column E. The column in the tables below labeled “Service Present” represents the column in the SRI spreadsheet labeled “1 - This domain is present; 2 - This domain is absent but mandatory; 0 - This domain is absent and not mandatory”. This is the user defined column where either a value of 0, 1, or 2 is input depending on the presence and necessity of the service, originally column F. These values are ultimately what determine the individual SRI scores for each domain, the overall SRI score for the project, and the SRI Class. This information will be used in the MATLAB App to calculate the relevant BACS Classes. The background colors have been added to adhere as closely as possible to the format of the spreadsheet. Table 70 below shows the smart ready services and functionality levels for the heating domain.

Table 70: SRI Input Data for the Heating Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
H-1a	Heat emission control	1	1	1
H-1b	Emission control for TABS (heating mode)	1	1	
H-1c	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	1	1	1
H-1d	Control of distribution pumps in networks	1	1	1
H-1f	Thermal Energy Storage (TES) for building heating (excluding TABS)	1	1	
H-2a	Heat generator control (all except heat pumps)	1	1	
H-2b	Heat generator control (for heat pumps)	1	1	0
H-2d	Sequencing in case of different heat generators	1	1	
H-3	Report information regarding heating system performance	1	1	0
H-4	Flexibility and grid interaction	1	1	1

This scenario for the heating domain describes this building as having

- central automatic control the heat emission
- outside temperature compensated control of distribution of fluid temperature
- on/off control of the distribution pumps in networks

- on/off control of heat generator for heat pumps
- no report information regarding heating system performance
- scheduled operation of the heating system
- no information regarding emission control for TABS, thermal energy storage for building heating, heat generator control excluding that for heat pumps, and sequencing in case of different heat generators

Table 71 shows the smart ready services and functionality levels for the domestic hot water domain.

Table 71: SRI Input Data for the Domestic Hot Water Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
DHW-1a	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	1	1	0
DHW-1b	Control of DHW storage charging (using hot water generation)	1	1	
DHW-1d	Control of DHW storage charging (with solar collector and supplementary heat generation)	1	1	1
DHW-2b	Sequencing in case of different DHW generators	1	1	
DHW-3	Report information regarding domestic hot water performance	1	1	0

This scenario for the domestic hot water domain describes this building as having

- automatic on/off control of DHW storage charging regarding direct electric heating or integrated electric heat pump
- automatic control of solar storage charging, supplementary storage charging, and demand-oriented supply of multi-sensor storage management
- no report information regarding DHW performance information regarding control of DHW storage charging using hot water generation or sequencing in case of different DHW generators

Table 72 shows the smart ready services and functionality levels for the cooling domain.

Table 72: SRI Input Data for the Cooling Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
C-1a	Cooling emission control	1	1	1
C-1b	Emission control for TABS (cooling mode)	1	1	
C-1c	Control of distribution network chilled water temperature (supply or return)	1	1	1
C-1d	Control of distribution pumps in networks	1	1	1
C-1f	Interlock: avoiding simultaneous heating and cooling in the same room	1	1	
C-1g	Control of Thermal Energy Storage (TES) operation	1	1	
C-2a	Generator control for cooling	1	1	0
C-2b	Sequencing of different cooling generators	1	1	
C-3	Report information regarding cooling system performance	1	1	0
C-4	Flexibility and grid interaction	1	1	1

This scenario for the cooling domain describes this building as having

- central automatic cooling emission control
- outside temperature compensated control of distribution network chilled water temperature
- on/off control of distribution pumps in network
- on/off control of cooling production for the generator control for cooling
- eport information regarding cooling system performance Central or remote reporting of current performance KPIs
- no automatic control for flexibility and grid interaction

- no information regarding emission control or TABS, interlock, control of thermal energy storage, sequencing of different cooling generators

Table 73 below shows the smart ready services and functionality levels for the ventilation domain.

Table 73: SRI Input Data for the Ventilation Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
V-1a	Supply air flow control at the room level	1	2	
V-1c	Air flow or pressure control at the air handler level	1	2	
V-2c	Heat recovery control:	1	2	
V-2d	Supply air temperature control at the air handling unit level	1	2	
V-3	Free cooling with mechanical ventilation system	1	2	
V-6	Reporting information regarding IAQ	1	2	

This scenario for the ventilation domain describes this building as having no smart services present, though the ”2” in each item of the ”Service Present” column stipulates that these services are mandatory.

Table 74 below shows the smart ready services and functionality levels for the lighting domain.

Table 74: SRI Input Data for the Lighting Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
L-1a	Occupancy control for indoor lighting	1	1	0
L-2	Control artificial lighting power based on daylight levels	1	1	2

This scenario for the lighting domain describes this building as having

- manual on/off switch regarding the occupancy control for indoor lighting
- automatic switching for the control of artificial lighting power based on daylight levels

Table 75 below shows the smart ready services and functionality levels for the dynamic building envelope domain.

Table 75: SRI Input Data for the Dynamic Building Envelope Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
DE-1	Window solar shading control	1	0	
DE-2	Window open/closed control, combined with HVAC system	1	0	
DE-4	Reporting information regarding performance of dynamic building envelope systems	1	0	

This scenario for the dynamic building envelope domain describes this building as having no smart services present, though the ”0” in each item of the ”Service Present” column stipulates that these services are not mandatory.

Table 76 below shows the smart ready services and functionality levels for the electricity domain.

Table 76: SRI Input Data for the Electricity Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
E-2	Reporting information regarding local electricity generation	1	1	2
E-3	Storage of (locally generated) electricity	1	1	
E-4	Optimizing self-consumption of locally generated electricity	1	1	0
E-5	Control of combined heat and power plant (CHP)	1	1	
E-8	Support of (micro)grid operation modes	1	1	
E-11	Reporting information regarding energy storage	1	1	
E-12	Reporting information regarding electricity consumption	1	1	1

This scenario for the electricity domain describes this building as having

- actual values and historical data regarding local electricity generation
- no optimizing self-consumption of locally generated electricity
- reporting on current electricity consumption on building level
- no information available on storage of locally generated electricity, control of combined heat and power plant, support of microgrid operation modes, or reporting information regarding energy storage

Table 77 below shows the smart ready services and functionality levels for the electric vehicle charging domain.

Table 77: SRI Input Data for the Electric Vehicle Charging Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
EV-15	Window solar shading control	1	0	
EV-16	Window open/closed control, combined with HVAC system	1	0	
EV-17	Reporting information regarding performance of dynamic building envelope systems	1	0	

This scenario for the electric vehicle charging domain describes this building as having no smart services present, though the ”0” in each item of the ”Service Present” column stipulates that these services are not mandatory.

Table 78 below shows the smart ready services and functionality levels for the monitoring and control domain.

Table 78: SRI Input Data for the Monitoring and Control Domain

Code	Smart Ready Service	Service Included	Service Present	Main functionality level
MC-3	Run time management of HVAC systems	1	1	1
MC-4	Detecting faults of technical building systems and providing support to the diagnosis of these faults	1	1	0
MC-9	Occupancy detection: connected services	1	1	0
MC-13	Central reporting of technical building system (TBS) performance and energy use	1	1	0
MC-25	Smart Grid Integration	1	1	0
MC-28	Reporting information regarding demand side management performance and operation	1	1	0
MC-29	Override of DSM control	1	1	0
MC-30	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	1	1	0

This scenario for the monitoring and control domain describes this building as having

- runtime setting of heating and cooling plants following a predefined time schedule
- no central indication of detected faults and alarms
- no occupancy detection
- no central reporting on TBS performance and energy use
- no smart grid integration
- no reporting information regarding demand of side management performance and operation

- no demand side management control
- no single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signal

Although only the first five domains are considered for the calculation of the BACS class using the MATLAB app, all nine are needed to calculate the SRI for the building. Using all of this input information, the spreadsheet then calculates the individual SRI values as well as the overall. Those results are shown below in Figure 19. Additionally, using the data from Tables 68 and 69, the impact scores are generated and shown below in Figure 20. Though this information is not used for the algorithm to calculate the BACS class, it is still useful to see a side-by-side comparison with the domain scores.

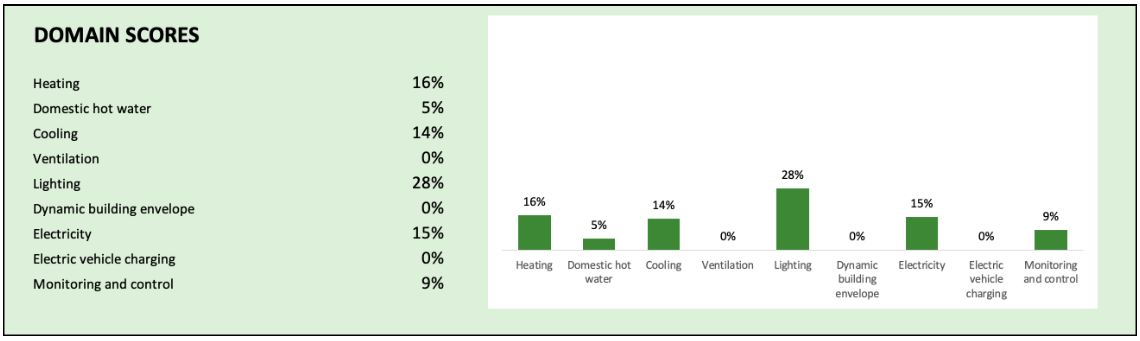


Figure 19: Individual SRI Domain Scores from the SRI Spreadsheet

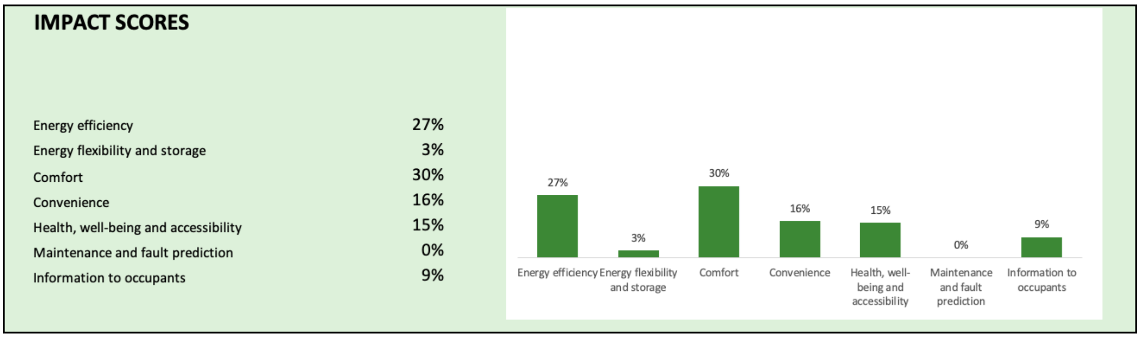


Figure 20: SRI Impact Scores from the SRI Spreadsheet

The overall SRI score calculated was 12% with an SRI class G. The domestic hot water domain exhibited very little smart capability at 5%, but in the context of an office building it is less important. While heating and cooling still exhibited quite low smart capability at 16% and 14%, respectively, lighting exhibited the highest at 28%. For an office building, the lighting domain is quite important. Now that all the relevant SRI information was calculated, the excel sheet could be used in the MATLAB app. The process of the functionality of the MATLAB app is summarized to completion below.

A folder for the project was created within the Documents folder labeled "Regione Lazio", and the excel spreadsheet with the SRI calculations using the scenarios from Figures 17 and 18 detailing the building information, Tables 66-69 detailing the domain weightings and the impact weightings, and Tables 70-78 detailing the functionality levels of all smart ready services from all nine domains was copied into it. This allowed for some organization once the MATLAB app ran to pull data and save results in the same location. Next, within the app, the file name for the completed excel spreadsheet and the described folder location are input into the relevant text boxes. Once the file and location name were correctly entered without spaces—a stipulation of MATLAB—the *Import* button could be pressed. This pulled the necessary data of the SRI functionality for the relevant 25 smart ready services along with their descriptions and corresponding BACS values. An image of the populated data table with this information is shown below in Figure 21.

Domain	Smart Ready Service	SRI Functionality	Description	BACS
Heating	Heat emission control	1	Central automatic control (e.g. central thermostat)	D
Heating	Emission control for TABS (heating mode)	NaN		NA
Heating	Control of distribution fluid temperature (supply or ret…	1	Outside temperature compensated control	D
Heating	Thermal Energy Storage (TES) for building heating (…	NaN		NA
Heating	Heat generator control (all except heat pumps)	NaN		NA
Heating	Heat generator control (for heat pumps)	0	On/Off-control of heat generator	D
Heating	Sequencing in case of different heat generators	NaN		NA
DHW	Control of DHW storage charging (with direct electric…	0	Automatic control on / off	D
DHW	Control of DHW storage charging (using hot water g…	NaN		NA
DHW	Control of DHW storage charging (with solar collecto…	1	Automatic control of solar storage charge (Prio. 1) a…	C
Cooling	Cooling emission control	1	Central automatic control	D
Cooling	Emission control for TABS (cooling mode)	NaN		NA
Cooling	Control of distribution network chilled water temperat…	1	Outside temperature compensated control	C
Cooling	Control of distribution pumps in networks	1	On off control	C
Cooling	Interlock: avoiding simultaneous heating and cooling…	NaN		NA
Cooling	Control of Thermal Energy Storage (TES) operation	NaN		NA
Cooling	Generator control for cooling	0	On/Off-control of cooling production	D
Cooling	Sequencing of different cooling generators	NaN		NA
Ventilation	Supply air flow control at the room level	NaN		NA
Ventilation	Air flow or pressure control at the air handler level	NaN		NA
Ventilation	Heat recovery control: prevention of overheating	NaN		NA
Ventilation	Supply air temperature control at the air handling uni…	NaN		NA
Ventilation	Free cooling with mechanical ventilation system	NaN		NA
Lighting	Occupancy control for indoor lighting	0	Manual on/off switch	D
Lighting	Control artificial lighting power based on daylight levels	2	Automatic switching	B

Figure 21: App Input

The rows do not adjust height for the information that does not fit within the established column with; however, within the app this information is visible when the mouse hovers over the cell. Additionally, in the final exported PDF, the rows do adjust for the information that exceeds the established column width. This is to say that all information is available to the user within the app. Next, before the calculation process is initiated, the UI Table that accepts the energy consumption quantities was populated using the energy analysis document that describes the annual consumption from a given year [24]. That data is shown below in Figure 22.

Domain	Energy Use (kWh)
Heating	150810
DHW	26851
Cooling	150810
Ventilation	0
Lighting	327548

Figure 22: Energy Input

The information regarding the ventilation domain was not readily available; however, this will not be relevant, as the BACS class for this domain cannot be calculated, as there was no smart ready services present per Table 73. Once these two tables of completed information are populated. The calculation process can continue. This is accomplished once the *Calculate* button is pushed. Figure 23 below shows the completed UI Table of the results.

Domain	SRI Score (%)	Global BACS	Energy Saving (%)	Energy Saving (kWh)	Most Critical Service
Heating	15.8300	D	30.5600	4.6088e+04	1)Heat emission control, 2)Control of distribution flui...
DHW	5.3300	D	9.9100	2.6609e+03	1)Control of DHW storage charging (with direct elect...
Cooling	14.2400	D	36.3100	5.4759e+04	1)Cooling emission control, 2)Generator control for c...
Ventilation	0	NA	0	0	
Lighting	28.0000	D	9.0900	2.9774e+04	1)Occupancy control for indoor lighting,

Figure 23: App Results

The first column of SRI Scores are taken directly from the imported excel spreadsheet. This data matches directly with the values from Figure 19. The next column of Global BACS classes shown are all level D or NA. Immediately, it is apparent that each domain, except Ventilation, has a lowest BACS class of D, which dictates the overall BACS class. Regarding the ”NA” value shown in the Ventilation domain, in Figure 21 each SRI Functionality Level and Corresponding BACS Classes has a value of NaN and NA, respectively. This is dictated by the indication in Table 73 that shows that each relevant smart ready service within the Ventilation domain is “absent but mandatory”. This absence results in an incalculable SRI value and subsequent BACS class for this domain.

The next column calculates the energy saving percentage based on the data in Equation (2) and uses the factors from Table 36 as this is classified as a "non-residential" building type for office usage. Because each Global BACS class has a value of D, the energy saving percentages for all domains are based on the energy savings from changing from a BACS class of D to C. For the ventilation domain, because there is no calculable BACS class, it is impossible to calculate the corresponding energy saving percentage which is entirely dictated by this value. The value is represented by a 0%. Similarly for the next column, the energy saving values are based on the product of the energy saving percentage and the user-input energy use from Figure 22. Because of this, the cell for the ventilation domain is left blank.

Finally, for the last column each smart ready service corresponding to the individual BACS class D values are compiled into respective lists of which services need to be modified to move up to at least a value of C. Similarly to the rest of the cells in the row for the Ventilation domain, this cell is left blank because when there is no BACS class assigned, it cannot be determined which services need to be modified to achieve a higher class. Similarly to the longer descriptions of data included in Figure 21, the overflow data in the cells in this column are visible both within the app and the final exported PDF report.

Along with the data compiled in a tabular format, the app generates two bar charts visually representing the BACS classes and the SRI values. The former is shown below in Figure 24.

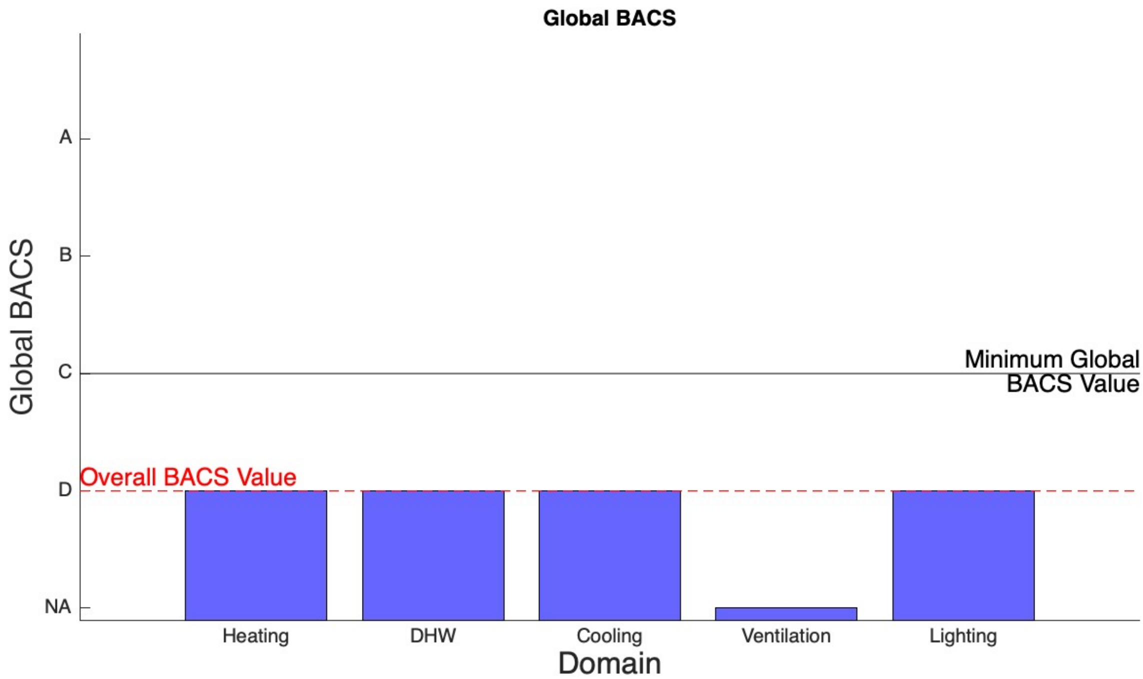


Figure 24: Global BACS Results

The overall BACS class for the project is determined by the singular lowest BACS class of the individual domains. Because each calculable domain yielded a value of D, this is the overall value, shown by the horizontal dotted line. Additionally, there is a solid black horizontal line representing the minimum necessary global BACS class. To be considered aligned with the requirements and goals outlined in UNI ISO EN 52120, this value of C is the minimum acceptable value. This building is currently off by an entire BACS class which means that significant changes to the building need to be made in the renovations. The next figure is a bar graph of the SRI values shown below in Figure 25.

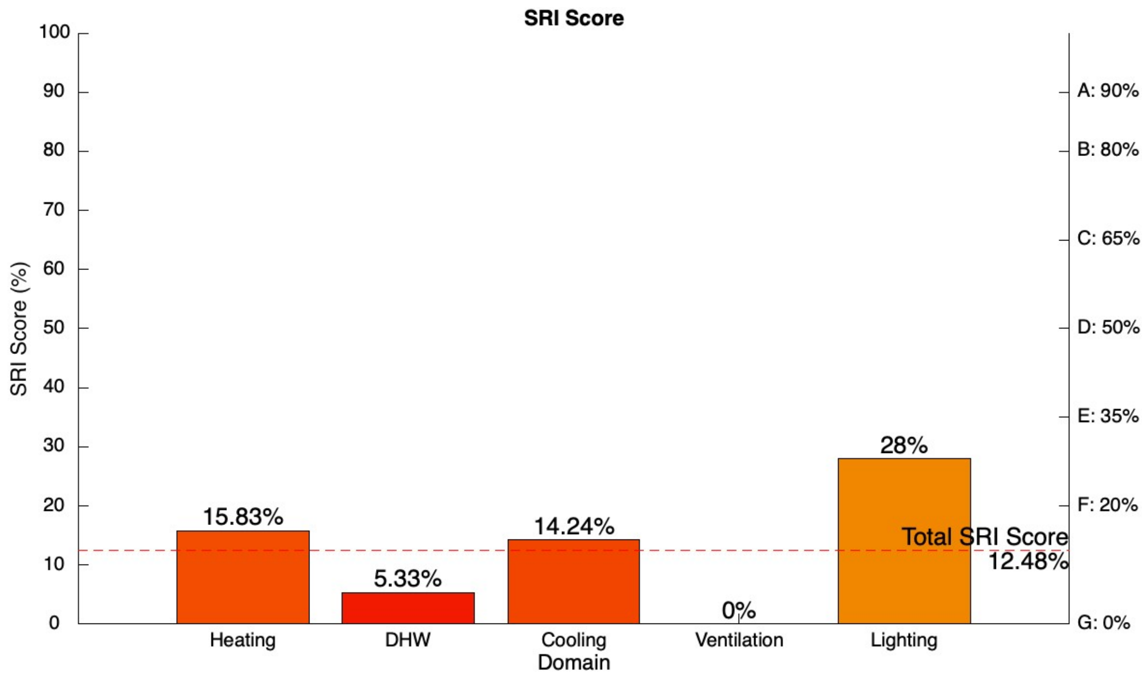


Figure 25: Overall SRI Results

For the purpose of this study, the SRI for the four domains not considered in the BACS calculation were not included in this graph. In addition to the individual SRI scores, the total SRI score is included. This value is not simply an average of the individual SRI scores. It considers all nine domains even if only these five were considered for the study and uses the weightings from Tables 66-69. The SRI classes, as well as their corresponding percentages, are also included on the secondary y-axis on the right hand side to visually show the relative classes of each domain and the discrepancy between the current SRI class and another.

This completes the procedure carried out for this case study and details each resulting data table and associated graph. However, as discussed in Section 6.2, the final step in using the app is to export the report. An example of the exported report using this information and calculated data described above is shown at the end of this thesis in Appendix A.

7.2 Discussion of Results

Based on the available data, this building as it currently stands exhibits very weak smart capability. The resultant 12% value of the SRI and the G rating mean that significant changes must be made. Based on the result of the procedure completed with the developed app, the individual levels assigned to the relevant smart ready services resulted in a BACS class of D for all domains except for ventilation which could not be calculated, as all services relevant to the domain were absent, though mandatory. While this data showed that this building shows very little smart capability, it shows that there are meaningful, clear changes that can be made to save energy and cut energy costs.

The global BACS class for the heating domain was found to be a D. This was due to the fact that the levels of the three smart ready services present—H-1a, H-1d, and H-2b—resulted in corresponding BACS classes of D, D, and D, respectively. By implementing individual room control for the heat admission, on/off control of the distribution pumps in network, and multi-stage control of heat generator capacity depending on the load or demand per the subsequent levels corresponding to a BACS class of C, the energy consumption associated with the heating of the building could potentially decrease by as much as 30.1%. This corresponds to an annual energy saving potential of 46.09 MWh based on the recorded energy consumption. Additionally, the introduction of the smart ready services not currently present at a minimum level corresponding to a BACS class of C could reinforce this reduction in energy use.

The global BACS class for the domestic hot water domain was found to be a D. This was due to the fact that the levels of the two smart ready services present—DHW-1a and DHW-1d—resulted in corresponding BACS classes of D and C, respectively. Though one of the services has a BACS class of C, the other's BACS class of D determines the overall class. By implementing automatic on/off control of domestic hot water storage charging and enabled scheduled charging per the subsequent level corresponding to a BACS class of C, the energy consumption relating to the domestic hot water could potentially decrease by as much as 9.91%. This corresponds to an annual energy saving potential of 2.661 MWh based on the recorded energy consumption. Additionally, the introduction of the smart ready services not currently present at a minimum level also corresponding to a BACS class of C could reinforce this reduction in energy use.

The global BACS class for the cooling domain was found to be a D. This was due to the fact that the levels of the smart ready services present—C-1a, C-1c, C-1d, and C-2a—resulted in corresponding BACS classes of D, C, C, and D, respectively. Though some of the services have a BACS class of C, the others' BACS classes of D determines the overall class. By implementing individual room cooling emission control and multi-stage control of cooling production capacity depending on the load or demand per the subsequent levels corresponding to a BACS class of C, the energy consumption associated with the cooling of the building could potentially decrease by 36.31%. This corresponds to an annual energy saving potential of 54.76 MWh based on the recorded energy consumption. Additionally, the introduction of the smart ready services not currently present at a minimum level also corresponding to a BACS class of C could reinforce this reduction in energy use.

The ventilation domain could not be assigned a BACS class according to this method because there were no smart ready services available. However, because of the nature of the criteria of the building established in Figures 17 and 18 it is necessary despite its absence. This can be amended by the introduction of the smart ready services that correspond to a minimum BACS class of C.

The global BACS class for the lighting domain was found to be a D. This was due to the fact that the levels of the smart ready services present—L-1a and L-2— resulted in a corresponding BACS class of D and B, respectively. Though the latter resulted in a BACS class of B, the former's BACS class of D determines the overall class. By implementing manual on/off switches and additional sweeping extinction signals regarding the occupancy control for indoor lighting per the subsequent level corresponding to a BACS class of B, the energy consumption associated with the lighting of the building could potentially decrease by 9.09%. This corresponds to an annual energy saving potential of 29.77 MWh based on the recorded energy consumption. In this case, all services were present, so this domain had the clearest, most accurate representation of this BACS class and associated energy reduction potential.

Though these results demonstrate a poor performance of building automation and control per the definition outlined in ISO EN 52120, there is large room for potential. The possibility of significantly decreasing the energy consumption when relatively simple upgrades are made in the process of essentially overhauling the building. At the time that this thesis was written, the cost of electricity in Italy was around .3291/kWh. This represents a value 14% higher than the EU average [25]. Creating a means of decreasing energy usage decreases costs significantly for energy that is not generated by the renewable means present in the building systems. According to a study conducted by Reuters, Italy is one of the European nations with the highest percentage of total energy coming from fossil fuels [26]. While that percentage is set to decrease, until that happens, finding means of decreasing energy usage, like this research proposes is essential to the longevity of Italy and the EU's demand for energy.

8 Conclusion

As mentioned in several sections of this thesis, the overall purpose of this research and development of the described algorithm is to reduce energy consumption of building systems. The app created during the development of this thesis serves to provide a means of achieving that. Though the implementation of regulations regarding the indices discussed does not yet have baseline requirements, it might require some time before processes are commonly implemented and taken into consideration in the mainstream. However, providing up to date information about the effects of building system and constantly identifying areas for improvement only serve to create frameworks for better, more sustainable buildings.

Because the SRI and the idea of assigning an alphabetical BACS class rating per UNI EN ISO 52120 are relatively new concepts, they are likely to be updated in the coming years. The SRI was officially debuted in 2018, while UNI EN ISO 52120 was established in 2022. The very nature of ISO standards is that they are flexible and account for changes and new systems. Similarly, within the very definition of the testing phase of the SRI outlined in Section 3.1, the SRI is promised to change based on the results of current research. This means that a new scale for the BACS, a new relevance of the domains involved, or any other change in the world of sustainability that is, by design, incredibly flexible has the possibility to change. This would require an update to the

means of calculating the SRI, the direct relationship between the SRI and the BACS class, and, within the context of this thesis, the nature of the algorithm and app described.

Despite the almost guaranteed changes that will be made to the defining factors, this app was designed to be as modular as possible, which will hopefully make it constantly relevant with these additions and updates. The hope for the future of this app is that it can continue to be used to provide greater context for the testing phase for the SRI. If the development of this app were to continue, adding a means of receiving updated energy costs to provide data on potential for cost saving would serve the overall purpose. From a financial perspective this is obviously the most important factor, so including that in the algorithm and the final report would only add value. Additionally, translating the energy savings potential to tons of carbon emitted based on the present and relevant domains and including it in this calculation would aid in providing context on the environmental front. There is room to build upon this work, but as it stands currently, it accomplishes what it was meant to within the provided scope.

As mentioned above in Section 3, there are no direct incentives at the moment associated with implementing efficient smart systems other than the potential for energy reduction. In the case of nations or corporations that are still refusing to find the urgency to make changes for the sake of reversing the damage done to the environment, this method at the very least outlines a concrete direction for significantly cutting costs. Because of the reasons described throughout this thesis, there is motivation for many parties to support the redesign of building systems and implement updated smarter ones. Building occupants not directly concerned with energy consumption and cost benefit from the resulting comfort and the health improvements, the groups financing projects and paying for the building energy have a direct means of cutting costs, and the parties concerned with the environmental benefits can witness tangible differences being made to energy consumption. Though future developments will most likely be necessary, this algorithm and the associated research provide a means of supporting this positive change.

References

[1] *Buildings and Construction*. European Commission, single-market-economy.ec.europa.eu/industry/sustainability/buildings-and-construction_en. Accessed 22 Nov. 2025.

[2] *Building Materials and the Climate: Constructing a New Future*. UNEP - UN Environment Programme, 12 Sept. 2023, www.unep.org/resources/report/building-materials-and-climate-constructing-new-future. Accessed 22 Nov. 2025.

[3] *Energy Performance of Buildings Directive*. (2023). European Comission. https://energy.ec.europa.eu/topics/energy-efficiency/energy-performance-buildings/energy-performance-buildings-directive_en. Accessed 22 Nov. 2025.

[4] S. van Roosmale, P. Hellinckx, J. Meysman, Verbeke, S., A. Audenaert. (2024). Building Automation and Control Systems for Office Buildings: Technical Insights for Effective Facility Management - A Literature Review. *Journal of Building Engineering*, 110943–110943. https://doi.org/10.1016/j.jobe.2024.110943

[5] *Smart readiness indicator*. (2018). European Commission . https://energy.ec.europa.eu/topics/energy-efficiency/energy-performance-buildings/smart-readiness-indicator_en. Accessed 22 Nov. 2025.

[6] Holnicki-Szulc, J., Motylewski, J., Kołakowski, P. (2008). *Smart Technologies for Safety Engineering*. Wiley Online Library. https://doi.org/10.1002/9780470758595. Accessed 22 Nov. 2025.

[7] Bermany, T. H. R., Osman, S. A., Yatim, M. Y. Md. (2025). A state-of-the-art analysis of base isolation systems and future directions for developing a novel multi-directional smart-hybrid isolation system integrated with earthquake early warning system for building structures. Results in Engineering, 25, 104501. https://doi.org/10.1016/j.rineng.2025.104501

[8] Day, J. K., Gunderson, D. E. (2015). Understanding high performance buildings: The link between occupant knowledge of passive design systems, corresponding behaviors, occupant comfort and environmental satisfaction. Building and Environment, 84, 114–124. https://doi.org/10.1016/j.buildenv.2014.11.003

[9] Jung, D., An, J., Hong, T. (2024). Exploring the Relationship Between Office Lighting, Cognitive Performance, and Psychophysiological Responses: A Multidimensional Approach. Building and Environment, 111863–111863. https://doi.org/10.1016/j.buildenv.2024.111863

[10] Ashton, D. (2025, March 18). Smart buildings, explained - here's what they mean for the built environment. University of the Built Environment. https://www.ube.ac.uk/whats-happening/articles/smart-buildings/. Accessed 22 Nov. 2025.

[11] *About BREEAM*. (2025). BREEAM. https://breeam.com/. Accessed 22 Nov. 2025.

[12] https://www.ube.ac.uk/whats-happening/articles/the-edge-amsterdam/. Accessed 22 Nov. 2025.

[13] Bloomberg. (2019). *The smartest building in the world*. Bloomberg.com. https://www.bloomberg.com/features/2015-the-edge-the-worlds-greenest-building/. Accessed 22 Nov. 2025.

[14] *SRI test phases*. (2024). European Commission. https://energy.ec.europa.eu/topics/energy-efficiency/energy-performance-buildings/smart-readiness-indicator/sri-eu-countries_en. Accessed 22 Nov. 2025.

[15] *SRI2MARKET - IEECP*. (2025, October 31). IEECP. https://ieecp.org/projects/sri2market/. Accessed 22 Nov. 2025

[16] European Commission. (2023). *Calculation Sheet Smart Readiness Indicator for Buildings* [Data set] . https://ec.europa.eu/eusurvey/runner/SRI-assessment-package

[17] Gusts Kossovics. (2022, June 15). *THE NEW EN ISO 52120 IS REPLACING EN 15232 - EU.BAC GUIDE — EUBAC*. European Building Automation and Controls Association. https://eubac.org/news/the-new-en-iso-52120-is-replacing-en-15232-eu-bac-guide/. Accessed 22 Nov. 2025.

[18] ISO. (2025). ISO - International Organization for Standardization. ISO. https://www.iso.org/home.html. Accessed 23 Nov. 2025.

[19] *Building Automation and Control Systems impact on EPC classes in Europe*. (2024, July). https://www.eubac.org/wp-content/uploads/2024/12/2024_eubac_Building-Automation-and-Control-Systems-Impact-on-EPC-Classes-in-Europe.pdf?utm_source=chatgpt.com

[20] Bonomolo, M., Zizzo, G., Ferrari, S., Beccali, M., Guarino, S. (2021). Empirical BAC factors method application to two real case studies in South Italy. *Energy, 236*, 121498–121498. https://doi.org/10.1016/j.energy.2021.121498

[21] CEN European Committee for Standardization. EN ISO 52120-1:2022, Energy performance of buildings - Contribution of building automation, controls and building management - Part 1: General framework and procedures.

[22] RINA Consulting. (2024). *UNI52120-SRI.xlsx* [Data set].

[23] DIREZIONE REGIONALE BILANCIO, GOVERNO SOCIETARIO, DEMANIO E PATRIMONIO AREA TECNICO-MANUTENTIVA. (2024). *B_RG_01.RELAZIONE GENERALE.pdf* [Data set].

[24] DIREZIONE REGIONALE BILANCIO, GOVERNO SOCIETARIO, DEMANIO E PATRIMONIO AREA TECNICO-MANUTENTIVA. (2024). *Regione Lazio - Diagnosi Energetica - 2017.pdf* [Data set].

[25] Eurostat. (2024). *Electricity price statistics*. European Commission. https://ec.europa.eu/eurostat/statistics-explained/index.php?title=Electricity_price_statistics. Accessed 22 Nov. 2025.

[26] Maguire, G. (2024, September 20). *Italy power costs stay sky high despite clean energy push*. Reuters. https://www.reuters.com/business/energy/italy-power-costs-stay-sky-high-despite-clean-energy-push-2024-09-20/. Accessed 22 Nov. 2025.

Appendix A

The results of the MATLAB app in report form are shown on the following pages.

Building Headquarters of the Regional Council of Lazio in Rome, Italy

RINA

Ava Mennin

22-Nov-2025

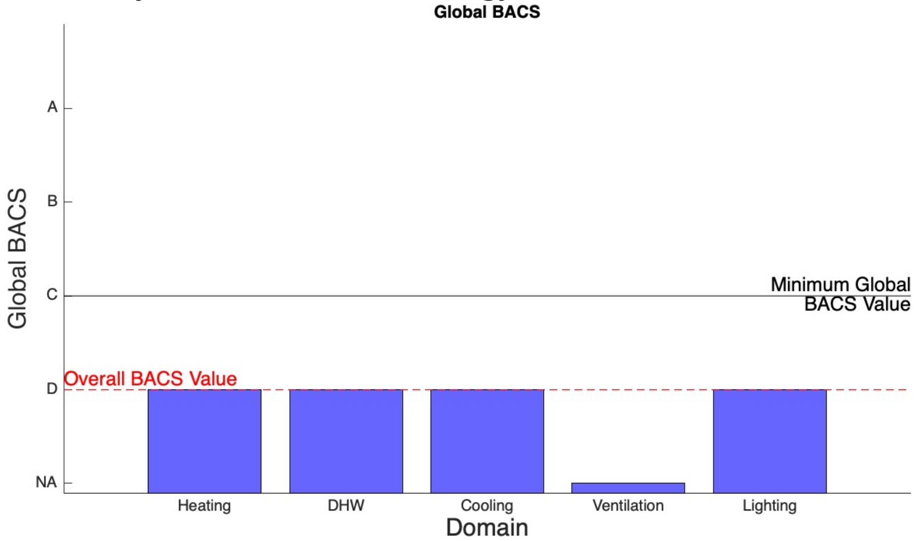
Chapter 1. Input

Domain	Smart Ready Service	SRI Functionality	Description	BACS Value
Heating	Heat emission control	1	Central automatic control (e.g. central thermostat)	D
Heating	Emission control for TABS (heating mode)			NA
Heating	Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks	1	Outside temperature compensated control	D
Heating	Thermal Energy Storage (TES) for building heating (excluding TABS)			NA
Heating	Heat generator control (all except heat pumps)			NA
Heating	Heat generator control (for heat pumps)	0	On/Off-control of heat generator	D
Heating	Sequencing in case of different heat generators			NA
DHW	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	0	Automatic control on / off	D
DHW	Control of DHW storage charging (using hot water generation)			NA
DHW	Control of DHW storage charging (with solar collector and supplymentary heat generation)	1	Automatic control of solar storage charge (Prio. 1) and supplementary storage charge	C
Cooling	Cooling emission control	1	Central automatic control	D
Cooling	Emission control for TABS (cooling mode)			NA
Cooling	Control of distribution network chilled water temperature (supply or return)	1	Outside temperature compensated control	C
Cooling	Control of distribution pumps in networks	1	On off control	C

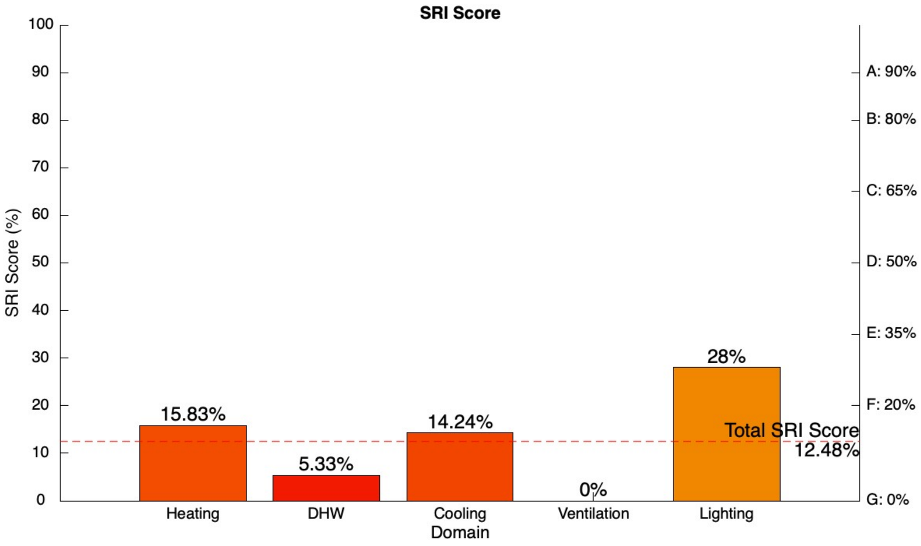
Cooling	Interlock: avoiding simultaneous heating and cooling in the same room			NA
Cooling	Control of Thermal Energy Storage (TES) operation			NA
Cooling	Generator control for cooling	0	On/Off-control of cooling production	D
Cooling	Sequencing of different cooling generators			NA
Ventilation	Supply air flow control at the room level			NA
Ventilation	Air flow or pressure control at the air handler level			NA
Ventilation	Heat recovery control: prevention of overheating			NA
Ventilation	Supply air temperature control at the air handling unit level			NA
Ventilation	Free cooling with mechanical ventilation system			NA
Lighting	Occupancy control for indoor lighting	0	Manual on/off switch	D
Lighting	Control artificial lighting power based on daylight levels	2	Automatic switching	B

Domain	SRI Score	Global BACS	Energy Saving %	Energy Saving Potential (kWh)	Improvements
Heating	15.83	D	30.56	46087.536	1)Heat emission control, 2)Control of distribution fluid temperature (supply or return air flow or water flow) - Similar function can be applied to the control of direct electric heating networks, 3)Heat generator control (for heat pumps),
DHW	5.33	D	9.91	2660.9341	1)Control of DHW storage charging (with direct electric heating or integrated electric heat pump),
Cooling	14.24	D	36.31	54759.111	1)Cooling emission control, 2)Generator control for cooling,
Ventilation	0	NA	0	0	
Lighting	28	D	9.09	29774.1132	1)Occupancy control for indoor lighting,

The following figure shows a bar graph representing the global BACS class of each domain. The dotted horizontal line represents the minimum global BACS value necessary to be considered energy efficient.



The following figure shows a bar graph of the SRI values for each domain taken directly from the SRI excel file. The dotted line represents the total SRI score.


SRI Score
SRI Score (%)
100
90
80
70
60
50
40
30
20
10
0
15.83%
5.33%
14.24%
0%
28%
Total SRI Score
12.48%
Heating
DHW
Cooling
Ventilation
Lighting
Domain
A: 90%
B: 80%
C: 65%
D: 50%
E: 35%
F: 20%
G: 0%