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SMART-READINESS ASSESSMENT OF A COMPLEX RESIDENTIAL BUILDING IN UKRAINE

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Abstract

Smart building concepts are a relevant topic for the Ukrainian building sector. Although the current policy is mostly dedicated to the improvement of the current energy-saving situation in the building stock, the concept discussed could provide valuable inputs in the realization of the existing strategy. For an assessment of the expected positive impact of the implementation of smart indicators on building operation and renovation processes, as well as the predictions of scenarios of the range of the application of smart instruments, the research presented proposes a thorough analysis of the building stock in Ukraine and, in a real pilot case, the assessment of smart-readiness indicators (SRI) for a complex multi-family building. The case scenarios used, which are derived on the basis of SRI and a processed questionnaire among the habitants, are considered as the reference foundation for a practical application and disseminating the concept for similar cases.

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Key words

- Smart-readiness indicator,
- Smart building,
- Technical systems,
- Energy consumption.

1 INTRODUCTION

Smart buildings are buildings that integrate and account for intelligence, enterprise, control, and materials, and the construction of an entire building system, with adaptability, not reactivity, at the core, in order to meet the drivers for a building's progress, i.e. energy and efficiency, durability, comfort, and satisfaction (Buckman, Mayfield, Beck 2014). The limits and definition of the smartness of a building is considered on the basis of a smart readiness indicator.

A smart readiness indicator should be used to measure the capacity of buildings to use information and communication technologies and of electronic systems to adapt the operation of buildings to the needs of occupants and the grid and to improve the energy efficiency and overall performance of buildings. A smart readiness indicator should raise awareness among building owners and occupants of the value behind building automation and electronic monitoring of technical building systems and should give confidence to occupants about the actual savings of those new enhanced functionalities [The European Parliament and The Council of the European Union 2018].

The following smart-readiness assessment for a complex residential building in Ukraine was carried out as a part of the PRECEPT project, which is aimed at transforming conventional residential buildings into highly efficient and proactive residential buildings [European Commission 2021].

The state-of-the art building stock in Ukraine.

General volume and composition. According to the State Statistics Service of Ukraine, the overall volume of the housing stock of Ukraine is presented in Tab. 1. The amount of residential and non-residential buildings and the percentage of the apartments equipped with the available types of services, according to the 2018 statistics, are shown in Tabs. 2 and 3.

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Tab. 1. *Housing stock of Ukraine [State Statistics Service of Ukraine 2020].*

Report Year	Total housing stock, mln. m² of total space	Average per person, m²	Total number of apartments, thsd
2020	1014.8	24.5	17,408

Tab. 2. *Services available in residential and non-residential buildings (Report Year 2018) [State Statistics Service of Ukraine 2018]*

	Total amount, thsd	Amount of the aparments equipped with							
		Water Pipes	Hot Water	Sewage System	Heating System			Gas Supply	
					central	individual	stove	natural	liquid
Ukraine	16,965	10,328	7,983	9,991	8,005	3,589	2,773	12,571	1,860
Dnipropetrovsk Region	1,465	1,009	698	965	922	191	82	1,249	64

Tab. 3. *Percentage of the equipped apartments in residential and non-residential buildings [State Statistics Service of Ukraine 2018]*

	Type of Equipment							
	Water Pipes	Hot Water	Sewage System	Heating System			Gas Supply	
				central	individual	Stove	natural	liquid
Ukraine	60.9	47.1	58.9	47.1	21.2	16.4	74.1	11.0
Dnipropetrovsk Region	68.9	47.7	65.9	63.0	13.1	5.6	85.3	4.4

The analysis of the housing stock in Ukraine showed that, in fact, every fourth inhabitant of the city lives in residential buildings that have already exhausted their operational resources and are in an unsatisfactory technical condition. The existing housing stock requires a significant amount of work on its repair and reconstruction. Most of the housing stock of Ukraine is in an unsatisfactory technical condition due to insufficient funding for its maintenance; there is a tendency of premature aging of the housing stock (Moroz 2016).

Energy-consumption characteristics. According to (Predun 2017), centralized systems prevail in the structure of the heat supply of settlements of Ukraine. They include the following structural elements:

1) heat sources - boilers of various types (almost 100,000) or thermal power plants (about 250); the main type of fuel - natural gas (for boilers - up to 50%, for CHP - up to 80%) [7], which comes from urban gas distribution networks and in some cases - large CHPs - from main gas pipelines;
2) underground water heating networks, which are laid, as a rule, in impassable channels (the length of the main and distribution heating networks (with the exception of self-heating networks of industrial enterprises) is almost 25,000 km in two-pipe calculations, including: municipal heating networks – 20,800 km with a diameter from 50 to 800 mm; the condition of most heating networks is unsatisfactory: more than 38% of heating networks have been operating for more than 25 years, 53% - for more than 10 years, and only 9% of heating networks have a service life of less than 10 years) [Ministers Cabinet of Ukraine 2017];
3) heating points (individual or central), which are connected to the city heating networks, and in which the heating and hot water supply systems are connected, respectively, of a separate house or their group.

Ukrainian regulations in the building stock adaptation to the smart systems. Currently, there is no special regulation or state strategy for the wide adaption of smart systems for the operation of the Ukrainian building stock. Taking into account the overall low level of the energy efficiency of the old buildings, which form the greatest part of the living spaces, the government policies are concentrated on this issue.

Considering the EU approaches, a system of normative documents in Ukraine has been developed, which is aimed at stimulating the introduction of effective technical solutions into construction practice. To date, a number of standards have been developed that regulate the requirements for methods of assessing energy efficiency, energy certification, the energy audit of buildings, rationing costs and losses. Legal issues in this aspect are regulated by the laws of Ukraine, the Energy Strategy of Ukraine to 2035, as well as the latest standards that have been developed to organize and to promote energy efficiency among stakeholders.

The laws of Ukraine have been adopted to attract investment to budget institutions and create an energy service market. Draft laws have been developed, i.e., “On Commercial Accounting of Public Utilities”, to ensure consumer protection in the field of public utilities through the introduction of mandatory accounting of thermal energy, hot and drinking water; “On the Energy Efficiency Fund” and “On the Energy Efficiency of Buildings”, which requires energy efficiency certification for new, state and municipal buildings, for the sale / lease of buildings, and for state support (Shovkalyuk 2017).

Digitalization in the building operation sector in Ukraine. The development of the market of intelligent building management systems in Ukraine depends on several factors, the most important of which are construction trends and the presence of wealthy customers who are willing to pay a lot of money for the automation of their homes.

The average “smart home” project for a private dwelling costs about USD 15,000 (in the “elite” segment, the minimum

cost of a set of the controller and touch panel, including the system programming functions, will cost more than USD 20,000). But a large building automation project (BMS) costs even more, i.e., about USD 500,000. But the number of orders in this area is significantly lower than that in the segment of the automation of private housing.

In general, despite the versatility of integrators working in both segments, their specialization is already evident. Some pay more attention to the field of housing automation, such as "Avisat" and "Legrand"; others pay more attention to the BMS segment ("Network Standard" or "Inteldome"). The division of the market into two segments, i.e., building automation (BMS) and housing automation ("smart home"), is just the tip of the iceberg. It should be borne in mind that buildings with different purposes (offices, hotels, shopping malls) require different approaches for the design and construction of the systems.

The IBMS market in Ukraine is at the initial stage of its formation. Limited demand remains the main deterrent to this area, as the purchasing power of the country's population has not yet recovered the level relative to the pre-crisis one of 2013. The main factors that negatively affect the development of this market in the country are as follows:

- poor awareness of the potential users of the IBMS capabilities;
- low purchasing power of Ukrainians and the high cost of equipment for such systems;
- approximately twice as much behind European countries in terms of Internet technology coverage of the country's population.

Grounding/justification of smart-readiness assessment in Ukrainian conditions. The Smart Readiness Indicator allows for rating the capability of buildings to adapt their operation to the needs of the occupant by also optimizing the energy efficiency and overall performance. Such information gives the possibility of promoting and popularizing smart solutions among building users, owners, tenants, and smart service providers, as the value of smart buildings becomes more tangible for them. Thus, a smart-readiness assessment is a powerful instrument for the broad implementation of smart technologies in Ukraine towards increased energy efficiency and well-being in residential buildings.

2 MATERIALS AND METHODS

2.1 Methodology of the questionnaire and Smart Readiness Indicator assessment

A detailed method (Method B [European Commission 2020]) was used to assess the Smart Readiness Indicator. This method involves interviewing the users to identify the current state of the building's "smartness", and the user's knowledge of smart technologies, indoor comfort and well-being. The interviews and Smart Readiness Indicator assessment were done by trained assessors familiar with the specifics of the Panorama Complex.

The questionnaire, which contains nine focus areas, was developed to obtain the basis for an in-depth analysis; it covers the building, general psychographic questions, well-being and the indoor comfort rating, the user's experience, the current energy performance, a structural analysis of the building, the facilities, the infrastructure, etc. The questionnaire developed was based on the methodology for EU countries [European Commission 2020] but considered its application to Ukrainian realities (e.g., the current status and preferred functions of building management systems, equipment for the application of renewable energy sources and systems of maintenance and control for indoor conditions according to the market available solutions). It should be mentioned here that the questionnaire was similar for all the consortium members of the PRECEPT project, which involves EU countries as well [European Union's Horizon 2020].

The questionnaire developed shows for each type of energy (heating, hot water supply, ventilation, cooling, electricity):

- the sources used to generate heat energy and cold;
- the combination of sources used for the energy and electrical supply (traditional or renewable);
- the amount of electricity consumed when generating and consuming all types of energy;
- the methods of recording and control of the loads and consumption of all types of energy for the separate apartments and for the house as a whole;
- the methods of managing consumption of all types of energy for the separate apartments and for the house as a whole.

At the same time, all possible options for combining the use of thermal and electrical energy and hot water are considered. The levels of the control and monitoring of hot water and electrical consumption for heating and ventilation, hot water consumption for domestic needs, and consumption of electricity for cold supply needs can be identified.

The Smart Readiness Indicator (SRI) was obtained in the form of a percentage that expresses the smart readiness of the building. The higher the percentage, the smarter the building. The methodology for the SRI calculations uses the following general sequencing [European Commission 2020].

Step 1. Triage process to define relevant smart-ready services in the building assessed.

Step 2. Determination of the functionality level of each smart-ready service through a visual inspection or technical documentation analysis.

Step 3. Calculation of the impact of the criterion scores as follows:

$$I(d,ic) = \sum_{i=1}^{N_d} I_{ic}\left(FL(S_{i,d})\right), \tag{1}$$

where: d is the number of the technical domain; ic is the number of the impact criterion in question; Nd is the total number of services in the technical domain; $S_{i,d}$ is service i of the technical domain d; $FL(S_{i,d})$ is the functionality level of service Si,d available in the building; $I_{ic}(FL(_{S_{i,d}}))$ is the impact criterion score of service $S_{i,d}$ for impact criterion number ic, according to the service's functionality level; and $I(d,ic)$ is the impact criterion score of domain number d for impact criterion number ic.

Step 4: Calculation of the maximum impact scores as follows:

$$I_{\max}(d,ic) = \sum_{i=1}^{N_d} I_{ic}\left(FL_{\max}(S_{i,d})\right), \tag{2}$$

where: $FL_{max}(S_{i,d})$ is the highest functionality level of service $S_{i,d}$ according to the smart-ready service catalogue; $I_{ic}FL_{max}(S_{i,d})$ is the impact criterion score of service Si,d for its highest functionality level; and $I_{max}(d,ic)$ is the maximum impact criterion score of domain number d for the impact criterion number ic.

Step 5. Determination of the smart-readiness scores for each impact criteria (expressed as a percentage) as follows:

$$SR_{ic} = \frac{\sum_{d=1}^{N} W_{d,ic} \cdot I(d,ic)}{\sum_{d=1}^{N} W_{d,ic} \cdot I_{\max}(d,ic)} \cdot 100\,, \tag{3}$$

where: d is the number of the technical domain; N is the total number of technical domains; $W_{d,ic}$ is the weighting factor expressed as a percentage of technical domain number d for the impact criterion number ic; and SR_{ic} is the smart readiness score for the impact criterion number ic.

Step 6: Smart-readiness scores along the three EPBD key capabilities (namely, the energy performance of the building, the building users, and the energy grid) as follows:

$$SR_c = \sum_{ic=1}^{M} W_c(ic) \cdot SR_{ic}\,, \tag{4}$$

where: SR_C is the smart readiness score for key capability c; M is the total number of impact criteria; $W_C(ic)$ is the weighting factor expressed in the percentage of impact criterion number ic for key functionality c; and SR_{ic} is the smart readiness score of impact criterion number ic.

Step 7: Determination of the total smart-readiness score for a building by weighing the calculated smart-readiness scores of the three key EPBD capabilities as follows;

$$SR = \sum \frac{1}{3} SR_c\,, \tag{5}$$

where: SR is the total smart readiness score; and SR_C is the smart readiness score for key capability c.

The SRI gives the score according to nine domains: the heating system, domestic hot water, cooling system, controlled ventilation, lighting, dynamic envelope, and electricity (renewables & storage), electrical vehicle charging, and monitoring and control. Services within each domain are evaluated regarding the impact they provide to the building, its users and the energy grid. For each domain, the different functionality levels are defined, i.e., from Level 0 as non-smart default to Level 3 (or 4, depending on the domain type) as the maximum smart. The impact criteria in the proposed SRI are energy savings, maintenance and fault predictions, energy flexibility and storage, comfort, convenience, well-being and health and information to the occupants. The general structure of the SRI domains and impact criteria are shown on Fig. 1.

After the SRI score is obtained, the different use case scenarios were developed to propose the possibilities increase the smartness of the building.

Summarizing all the above-mentioned, the flowchart for the adopted SRI assessment methodology is presented in Fig. 2.

2.2 Description of the building

For carrying out the assessment of the Smart Readiness Indicator, the Panorama pilot site was selected. The illustration of the Panorama pilot site building complex is shown in Fig. 3.

The Panorama pilot site building complex consists of five multi-family residential buildings, including two 19-srorey buildings and three 24-storey buildings. The apartments in the complex contain various amounts of rooms of various floor areas, with different numbers of occupants.

The complex consists of 1,008 one-, two-, and three-room apartments with 3 levels of parking. The area of the pilot apartments ranges from 46.3 to 121 m^2, with free layouts and a combination of apartments available.

The buildings' construction mainly consists of reinforced concrete, especially in their foundations. Each building is covered with mineral insulation of a 8 cm thickness. Special attention was paid to the roofs, which were insulated with 8 cm stone wool and with a waterproofing coating. Windows are double glazed with a U-value from 0.85 to 2.42 W/m²K (depending on the size and number of the window panels).

Technical solutions of the buildings in the Panorama complex include ventilated energy- saving facades; energy-saving panoramic glazing; aluminum stained-glass windows; finishing screeds with sound insulation layer; a roof boiler room; elevators with a lifting capacity of 1,000 kg; metal, fireproof, and shockproof entrance doors; fire alarms, smoke extraction, and a fire ex-

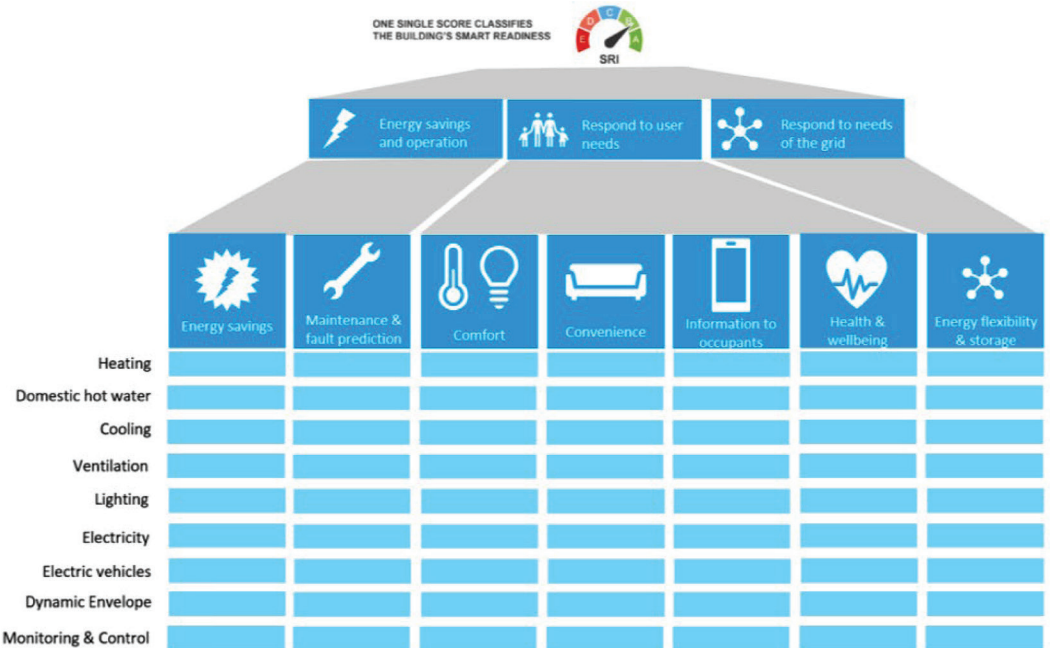


Fig. 1. *SRI structure of domains and impact criteria [European Commission 2020]*

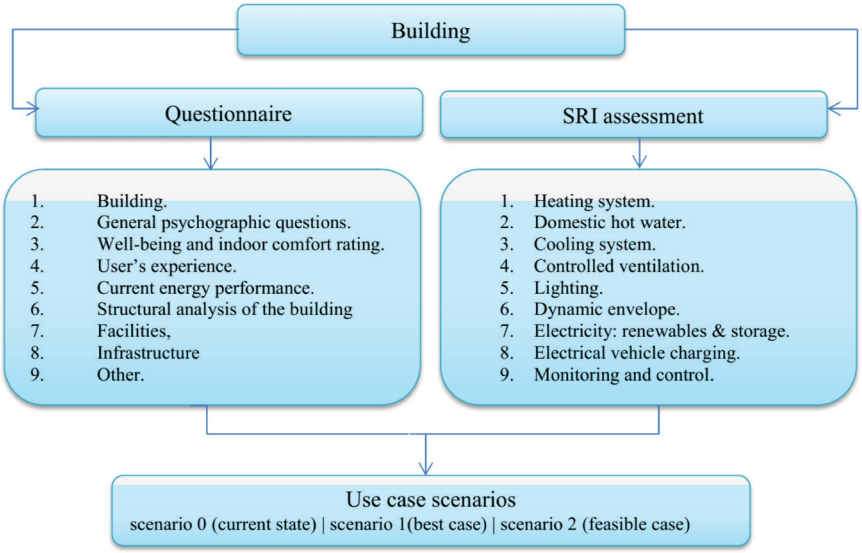


Fig. 2. *Flowchart of the SRI assessment method*



Fig. 3. *Panorama pilot site complex of buildings*

tinguishing system; one station to charge electric vehicles; and a 24/7 security system.

The Panorama complex is located in the city of Dnipro in central Ukraine; therefore, the climatic conditions for the heating systems are as follows:

– average temperature of the coldest five-day period, $t°_{winter} = -24°C$,
– average outdoor temperature for the heating period (from October 15 to April 15), $t_{average} = -0.2°C$;
– duration of the heating period, $n_h = 175$ days;
– average air velocity for the coldest month, V = 5.2 m/s;
– heat carrier for the heating system – hot water, with the parameters: $t_1^p = 950°C$; $t_2 = 70°C$;
– cooling: $t°_{summer} = 300°C \div 350°C$;

Available utilities and facilities in the pilot buildings include electricity, heating and a water supply, as well as the internet and cable television. Each apartment additionally has a TV, refrigerator, water heater, microwave, dishwasher, washing machine, and dryer.

The apartments have different levels of energy consumption according to the facilities installed:

– electricity;
– hot water for the hot water supply;
– hot water for the heating systems;
– cold water.

DHW is centrally heated by heating from the building gas boiler-room on the roof;

individual heating comes from an electric boiler or heat pump and with electric heating up to temperatures exceeding hot water = 55°C.

The heating system is centralized from the roof gas boiler-room; the individual (apartment- by-apartment) system is from electric boilers or heat pumps.

The cooling system includes single air conditioners powered by electricity or heat pumps. No smart devices are installed. There are stations to charge electric cars.

3 RESULTS AND DISCUSSION

3.1 Questionnaire results

The questionnaires gave a general picture of the consumption of all types of energy by the apartments and the house as a whole and the manageability of the energy consumption.

The analysis of the responses to the general psychographic questions has shown that each apartment can accommodate from two to four (or five) people of the different social statuses:

– young families with two or three children;
– families of two family members from 20 to 70 years old;
– youth groups (students, working youth, etc.).

The tenants have good digital literacy, as they often use electronic devices and, in most cases, have no problems with finding, comprehending, and sharing information online. Energy consumption control is only performed through the data collected from stationary meters for electricity, cold water, heating and hot water.

As for the well-being and indoor comfort, the occupants have no problems with humidity in their apartments in winter or summer, but they are not satisfied with the air quality inside their apartment. There is a general exhaust ventilation system installed

in each building. However, there is no general air conditioning system across the entire building. An individual air conditioning system is installed in every apartment of the buildings, so the tenants find the temperature conditions in the apartment satisfactory. The quality of the tap water is quite satisfactory for technical needs (laundry, shower). As for cooking and drinking, the residents have individual filtering devices installed for additional water purification. There is enough natural light, and the illumination of the apartments during daytime is satisfactory, but there is zero shading of the windows by either natural or artificial factors. The acoustic conditions are comfortable; no noise can be heard from the outside or from neighboring apartments, as well as from the elevator inside the building.

3.2 SRI results

An Excel-based tool was used to perform the assessment of the SRI of the Panorama building complex [European Commission 2020]. The SRI calculations assumed the performing of several steps by the assessors.

As the first step, the assessor needed to input the necessary information about the building, choose the technical systems present in the building and provide their basic characteristics. This information is presented in Tabs. 4 and 5.

Tab. 4. *General information about the Panorama complex buildings for the Excel-based tool*

Information needed	**Description**
Building type	**Residential**
Building usage	**Large multi-family** *house*
Location	**Dnipro, Ukraine**
Climate zone	**North-East Europe**
Net floor area of the building	10,000 – 25,000 m²
Year of construction	> 2010
Building state	Renovated

As the next step, the assessor inputted the functionality levels for each technical service present in the building. The list and description of the impact domains as well as the functionality level for the technical services according to the assessor's inspection are shown in Tab. 6.

Tab. 5. *The technical systems present in the Panorama complex buildings and their brief characteristics for the Excel-based tool*

Technical system	*Presence*	*Characteristic*	*Description*
Heating system	Yes	Emission type	Other hydronic system (e.g. radiators)
		Production type	Central heating - combustion
		Thermal energy storage	No storage present
		Multiple generators	Single generator
Domestic Hot Water	Yes	Production type	Electric (direct or integrated heat pump)
		Storage present	Storage present
		Solar collector	No solar collector present
		Multiple generators	Single generator
Cooling system	Yes	Emission type	Non-hydronic system (e.g. all- air)
		Thermal energy storage	No storage present
		Multiple generators	Single generator
Controlled ventilation	No	Not to be assessed	-
Lighting	Yes	-	-
Dynamic Envelope: automated windows & blinds	No	Not to be assessed	-
Electricity: renewables & storage	No	Not to be assessed	-
Electric Vehicle Charging	Yes	On-site parking spots	On-site parking
		Electric vehicle charging spots	EV charging

Tab. 6. *Functionality level of the technical services of the Panorama complex of buildings for the Excel-based tool*

Code	Description	Service	Main functionality level as inspected by the SRI assessor	Functionality level
Heating	Heat control - demand side	Heat emission control	2	Individual room control (e.g. thermostatic valves, or electronic controller)
	Heat control - demand side	Emission control for TABS (heating mode)	0	No automatic control
	Heat control - demand side	Control of distribution fluid temperature (supply or return air flow or water flow)	1	Outside temperature compensated control
	Heat control - demand side	Control of distribution pumps in networks	3	Variable speed pump control (pump unit (internal) estimations)
	Heat control - demand side	Thermal Energy Storage (TES) for building heating (excluding TABS)		Continuous storage operation
	Control heat production facilities	Heat generator control (all except heat pumps)	2	Variable temperature control depending on the load (e.g. depending on the water supply temperature set point)
	Control heat production facilities	Heat generator control (for heat pumps)	0	On/Off-control of heat generator
	Control heat production facilities	Sequencing in case of different heat generators	0	Priorities only based on running time
	Information to occupants and facility managers	Report information regarding HEATING system performance	1	Central or remote reporting of current performance KPIs (e.g., temperatures, submetering energy usage)
	Flexibility and grid interaction	Flexibility and grid interaction	1	Scheduled operation of the heating system
Domestic hot water	Control DHW production facilities	Control of DHW storage charging (with direct electric heating or integrated electric heat pump)	1	Automatic control on / off and scheduled charging enable
	Control DHW production facilities	Control of DHW storage charging (using hot water generation)		Automatic control on / off
	Control DHW production facilities	Control of DHW storage charging (with solar collector and supplementary heat generation)	0	Manual selected control of solar energy or heat generation
	Control DHW production facilities	Sequencing in case of different DHW generators	0	Priorities only based on running time
	Information to occupants and facility managers	Report information regarding domestic hot water performance	0	None
Cooling	Cooling control - demand side	Cooling emission control	2	Individual room control
	Cooling control - demand side	Emission control for TABS (cooling mode)	0	No automatic control
	Cooling control - demand side	Control of distribution network chilled water temperature (supply or return)	0	Constant temperature control
	Cooling control - demand side	Control of distribution pumps in networks	0	No automatic control
	Cooling control - demand side	Interlock: avoiding simultaneous heating and cooling in the same room	0	No interlock
	Cooling control - demand side	Control of Thermal Energy Storage (TES) operation		Continuous storage operation
	Control cooling production facilities	Generator control for cooling	2	Variable control of cooling production capacity, depending on the load or demand
	Control cooling production facilities	Sequencing of different cooling generators		Priorities only based on running times
	Information to occupants and facility managers	Report information regarding cooling system performance	0	None
	Flexibility and grid interaction	Flexibility and grid interaction	0	No automatic control

Code	Description	Service	Main functionality level as inspected by the SRI assessor	Functionality level
Ventilation	Air flow control	Supply air flow control at the room level	0	No ventilation system or manual control
	Air flow control	Air flow or pressure control at the air handler level	0	No automatic control: Continuous supplies of air flow for a maximum load of all rooms
	Air temperature control	Heat recovery control:	0	Without overheating control
		prevention of overheating		
	Air temperature control	Supply air temperature control at the air handling unit level	0	No automatic control
	Free cooling	Free cooling with the mechanical ventilation system	0	No automatic control
	Feedback - Reporting information	Reporting information regarding IAQ	0	None
Lighting	Artificial lighting control	Occupancy control for indoor lighting	2	Automatic detection (auto on / dimmed or auto off)
	Control artificial lighting power based on daylight levels	Control artificial lighting power based on daylight levels	1	Manual (per room / zone)
Dynamic envelope	Window control	Window solar shading control	0	No sun shading or only manual operation
	Window control	Window open/closed control, combined with HVAC system	0	Manual operation or only fixed windows
	Feedback - Reporting information	Reporting information regarding performance of dynamic building envelope systems	0	No reporting
Electricity (renewables & storage)	Feedback - Reporting information	Reporting information regarding local electricity generation	0	None
	DER – Storage	Storage of (locally generated) electricity	0	None
	DER- Optimization	Optimizing self-consumption of locally generated electricity	0	None
	DER - Generation Control	Control of combined heat and power plant (CHP)	0	CHP control based on scheduled runtime management and/or current heat energy demand
	DSM- Storage	Support of (micro)grid operation modes	0	None
	Feedback - Reporting information	Reporting information regarding energy storage	0	None
	Feedback - Reporting information	Reporting information regarding electricity consumption	0	None
Electric vehicle (EV) charging	EV Charging	EV Charging Capacity	1	ducting (or simple power plug) available
	EV Charging – Grid	EV Charging Grid balancing	1	1-way controlled charging (e.g., including desired departure time and grid signals for optimization)
	EV Charging – connectivity	EV charging information and connectivity	0	No information available
Monitoring & Control	HVAC interaction control	Run time management of HVAC systems	0	Manual setting
	Fault detection	Detecting faults of technical building systems and providing support to the diagnosis of these faults	0	No central indication of detected faults and alarms

Code	Description	Service	Main functionality level as inspected by the SRI assessor	Functionality level
Monitoring & Control	TBS interaction control	Occupancy detection: connected services	1	Occupancy detection for individual functions, e.g., lighting
	Feedback - Reporting information	Central reporting of TBS performance and energy use	1	Central or remote reporting of real-time energy use per energy carrier
	Smart Grid Integration	Smart Grid Integration	1	Demand side management possible for (some) individual TBS, but not coordinated over various domains
	Feedback - Reporting information	Reporting information regarding demand side management performance and operation	0	None
	Override control	Override of DSM control	0	No DSM control
	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	Single platform that allows automated control & coordination between TBS + optimization of energy flow based on occupancy, weather and grid signals	0	None

According to the information provided in the last step, the charts of the impact scores for each impact criteria as well as the domain scores for different services are calculated and displayed. The impact criteria assessment is shown in Fig. 4, and the domain assessment is shown in Fig. 5.

The total SRI score obtained is 31%. Such results show great possibilities of increasing the degree of controllability of the storage and consumption of heat, cold, and electricity. The practical meaning of the SRI level is the revealing of possible measures to develop and implement an increase in the level of "smartness" of the energy management in the building.

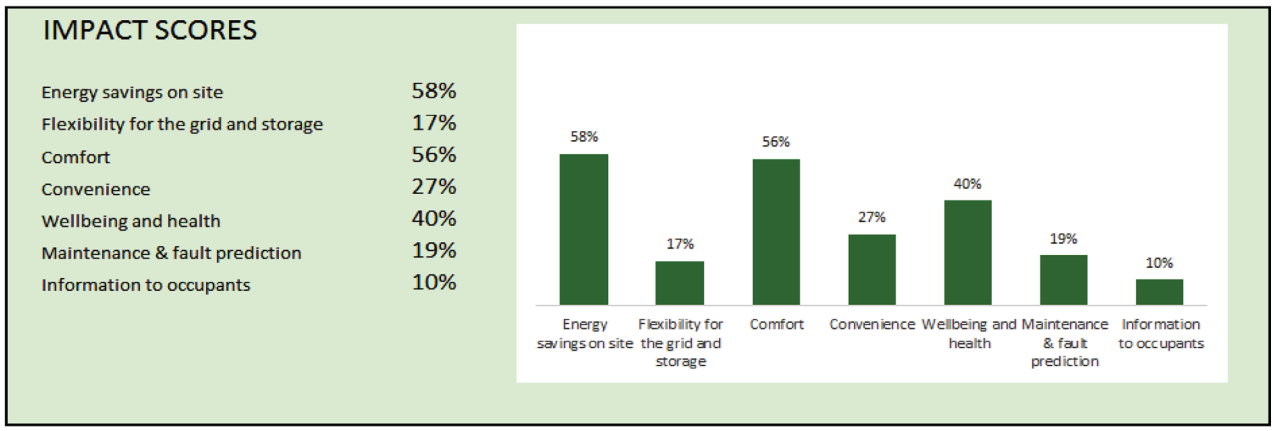


Fig. 4. *Impact assessment for the Panorama complex of buildings*

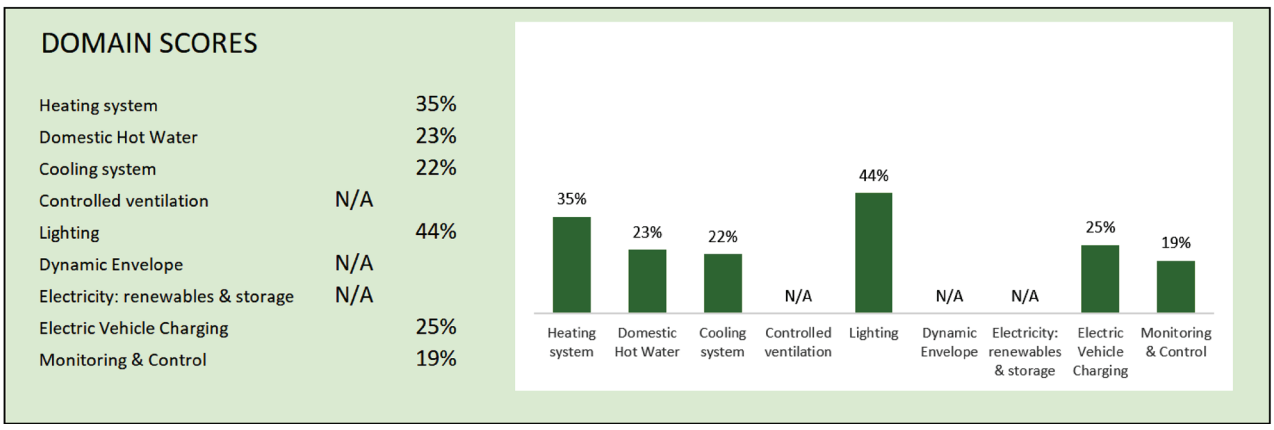


Fig. 5. *Domain assessment for the Panorama complex of buildings*

3.3 Development of the use case scenarios

After analyzing the thermal properties of the building envelope, the current state of the building's engineering equipment, and the control and regulation systems (security systems, all

pipeline engineering systems, systems that generate heat and cold, and electricity), the use case scenarios were developed. The user's requirements, literacy and ability to use the internet were also taken into account for this task. It was established that in the Panorama complex, the users have good digital literacy, as they often use electronic devices and do not have problems with finding, understanding, and sharing information online. They use electronics in moderation. Some users only monitor the room temperature and record their electricity consumption once a month. The users are satisfied with the maintenance of the building. They have a positive attitude towards new technologies for regulating energy consumption.

Three scenarios, which are associated with accounting (control, monitoring), and regulation of energy consumption by the apartments in the residential complex, were considered:

– use case scenario 0 - current state, what smart building technologies are currently present (corresponds to the SRI score obtained in the previous clause);
– use case scenario 1- best case scenarios, all smart building technologies that could be installed if there were no limitations;
– use case scenario 2 - feasible scenario, based on finances, country regulations etc., which can actually be executed in the scope of the project

The scenarios were compiled according to the catalog of Smart Ready services and their levels of functionality according to [European Commission 2020]. The future level of the SRI was obtained in the same way as for the current state of the building. The measures to implement all the use case scenarios and the future state SRI are presented in Tab. 7.

According to the recalculations when considering the feasible scenario, the future level of the SRI obtained is 63%.

3.4 Discussion

The purpose of the introduction of smart technologies is to create an intelligent system for managing all types of energy used by residents of houses. Thus, a certain uniformity of the technical solutions adopted is assumed in all the apartments, which, unfortunately, are not available in every building of the Panorama complex.

Each house is equipped with a roof boiler room, which is able to provide the heating systems and hot water for each apartment. At the same time, not all the apartments use heat from the roof boiler room. There are several dozen apartments in each house in which their hot water is prepared in electric boilers. Also, there are a number of apartments in each building that use air- to-water heat pumps for the heating systems. The rest of the apartments use hot water for the heating systems and hot water supply. Moreover, the systems in each apartment are different.

As for an analysis of the weather regulations of heat releases, since some apartments provide themselves with the generation of a heat carrier for a heating system, it will not be possible to carry out the weather regulation in full and correct the volume.

For these complex buildings, it could be recommended to extend the form of the questionnaire. This suggests that in the group of questions on electricity consumption, it will be necessary to note, for example, the volume of the boiler and its capacity. For the heating and hot water supply systems, it will be necessary to characterize each type of energy consumed. It is necessary to record where the windows are oriented, the area of the windows, and whether they have protective layers or other shading devices.

The possible increase of the SRI level is obtained through the development of the use case scenarios. The higher the SRI,

Tab. 7. *Use case scenarios for the Panorama complex*

№	Measures to implement	Use case scenario 0	Use case scenario 1	Use case scenario 2
1	Lightning control	x		
2	Microclimate controller		x	
3	Access controller		x	
4	Fire safety controller	x		
5	Accident prevention controller		x	
6	Security controller		x	
7	Multi room controller		x	x
8	Energy controller		x	x
9	WRA controller			
10	Territory service controller			
11	Smart home protocols & smart gateways		x	x
	SRI (future state)			63%

the less energy consumed in the apartments and the building as a whole; thus, the amount of CO_2 emissions decreases.

All the positions in the scenarios developed are aimed at free access to control and acquire information on the consumption of electricity and heat. The only positions that allow regulating the consumption of heat and electrical energy are the multifunctional room controller and energy regulator (lines 7 and 8 of the scenario table).

In each apartment, activities could be developed in relation to the installation of smart sockets, smart household appliances (smart refrigerators, smart washing machines, smart dishwashers, etc.), renewable energy source technologies (heat, cold, electricity), and technologies for the accumulation of electrical and thermal energy for the needs of the residents of a multi-storey building.

In the future, after a certain period of monitoring the consumption of all types of energy, a second questionnaire survey and recalculation of the SRI will be carried out. In this case, a possible option of the SRI calculations for the whole building and separately for the apartments selected can be considered. Such an approach helps to develop measures for a more effective smart transformation for the individual apartments and buildings in general.

The future work within the frame of the implementation of smart technologies in the buildings includes energy-saving assessments, decreasing of the carbon impact as well as improving the economic effectiveness of the building's smart-performance.

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REFERENCES

Buckman, A.H., Mayfield, M. and B.M. Beck, S. (2014) *What is a Smart Building?* Smart and Sustainable Built Environment, Vol. 3 No. 2, pp. 92-109. DOI: 10.1108/SASBE-01-2014-0003.

The European Parliament and The Council of the European Union (2018) *Directive (EU)* 2018/844 of the European Parliament and of the Council of 30 May 2018 amending Directive *2010/31/EU on the energy performance of buildings and Directive 2012/27/EU on energy efficiency*. Official Journal of the European Union, Brussels, Belgium, 2018. Available at: https://op.europa.eu/en/publication-detail/-/publication/a61a4eda-7380-11e8-9483-01aa75ed71a1/language-en (accessed at 10/10/2021).

State Statistics Service of Ukraine (2020) *Демографічна та соціальна статистика. Населені пункти та житло (Demographic and social statistics. Settlements and housing)*. Available at: http://ukrstat.gov.ua/operativ/menu/menu_u/if.htm (accessed at 10/10/2021) [in Ukrainian].

State Statistics Service of Ukraine (2018) *Житловий фонд України (Housing stock of Ukraine)*. Available at: http://ukrstat.gov.ua/druk/publicat/kat_u/2018/zb/07/zb_jf_2017_pdf.pdf (accessed at 10/10/2021) [in Ukrainian].

Moroz, N. V. (2016) *Розвиток системи управління житловим фондом в Україні (Development of housing fund management system in Ukraine).* Lviv Polytechnic National University, Lviv, Ukraine. Available at: http://ena.lp.edu.ua/bitstream/ntb/33864/1/avt_Moroz.pdf (accessed at 10/10/2021) [in Ukrainian].

Predun, K. M. (2017) *Підвищення енергоефективності існуючого житлового фонду України (Energy efficiency improvement of the current Ukrainian residential areas).* Urban development and spatial planning, Vol. 65, pp. 462–466. Available at: http://library.knuba.edu.ua/books/zbirniki/02/2017/201765.pdf (accessed at 10/10/2021) [in Ukrainian].

Cabinet of Ministers of Ukraine (2017) *Енергетична стратегія України на період до 2035 р. Безпека, енергоефективність, конкурентоспроможність (Energy strategy of Ukraine for the period up to 2035. Security, energy efficiency, competitiveness)*. Available at: http://mpe.kmu.gov.ua/minugol/control/publish/article?art_id=245234085 (accessed at 10/10/2021) [in Ukrainian].

Shovkalyuk, M.M. (2017) *Підвищення енергоефективності будівельного фонду шляхом удосконалення законодавчої та нормативної бази (Improving the energy efficiency of the construction fund by improving the legislative and regulatory framework)* IV International scientific-technical and educational-methodical conference "Energy management: state and prospects of development - PEMS'17", National Technical University of Ukraine "Igor Sikorsky Kyiv Polytechnic Institute", Kyiv, Ukraine, p. 131. Available at: http://confopcb.iee.kpi.ua/public/conferences/51/PEMS-2017/ZbirnyktezPEMS2017.pdf (accessed at 10/10/2021) [in Ukrainian].

European Commission (2020) *Final report on the technical support to the development of a smart readiness indicator for buildings*. Available at: https://ec.europa.eu/energy/studies_main/final_studies/final-report-technical-support- development-smart-readiness-indicator_en (accessed at 10/10/2021).

European Union's Horizon (2020) *Precept Project | Less Energy - Smarter Buildings*. Available at: https://www.precept-project.eu/ (accessed at 23/02/2022)