Supplementary Material

Charting Climate Adaptation Integration in Smart Building Rating Systems: A Comparative Study of Four Schemes

Ahmed Khoja1\*, Olena Danylenko

\* Correspondence: Ahmed Khoja: Khjoa@hm.edu

# 1 Assessing the Inclusion Climate Change Adaptation Measures in the Performance Requirements of in The SmartScore Label

Table 1.1 Rating of the SRI adaptation requirements to the climate change hazard of flooding, flash floods and groundwater rise

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard flooding, flash floods and groundwater rise | Comments  |
| SRI Indicator  | Rating  |  |
| Structures | DE-4 Reporting information regarding performance of dynamic building envelope systems | 1 | Position of each product, fault detection, predictive maintenance, real-time & historical sensor data can improve the reliability of the system and resilience against adverse climate impacts  |
| Water, wastewater, and sanitation systems | DHW-3 Report information regarding domestic hot water performance | 0 | The SRI includes the requirement of Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault, nevertheless its limited to hot water supply and not wastewater and freshwater. |
| MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | Central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the water and sanitation systems in face network disturbance due climate impact (Barrelas et al, 2021). But it is limited to the active parts of the system.  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | H-1c Storage and shifting of thermal energy | 2 | The SRI includes the requirement of HW storage vessels controlled based on external signals (from BACS or grid), which can serve domestic need in case of network disturbances  |
| H-1f Thermal Energy Storage (TES) for building heating (excluding TABS) | The SRI includes the requirement of Heat storage capable of flexible control through grid signals (e.g. DSM), which can serve domestic need in case of network disturbances |
| H-4 Flexibility and grid interaction | The SRI includes the requirement of optimized control of heating system based on local predictions and grid signals (e.g. through model predictive control), which can prepare the system in advance to adverse climate impacts. |
| H-3 Report information regarding heating system performance | The SRI includes the requirement of Central or remote reporting of performance evaluation including forecasting and predictive management and fault detection. This can improve the resilience of the heating system in fact of climate change adverse impact (Barrelas et al, 2021) |
| C-1g control of Thermal Energy Storage (TES) operation | Cold storage capable of flexible control through grid signals (e.g. DSM). This can improve the resilience of the cooling system in face network disturbance  |
| C-3 Report information regarding cooling system performance | Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection. This can improve the resilience of the cooling system in fact of climate change adverse impact |
| C-4 Flexibility and grid interaction | Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control). This can improve the resilience of the energy system in face network disturbance  |
| E-3 Storage of (locally generated) electricity | On site storage of energy (e.g. electric battery or thermal storage) with controller optimizing the use of locally generated electricity and possibility to feed back into the grid. This can improve the resilience of the energy system in face network disturbance due climate impact |
| E-2 Reporting information regarding local electricity generation | Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection. This can improve the resilience of the energy system in face network disturbance due climate impact |
| E-8 Support of(micro)grid operation modes | Automated management of (building-level) electricity consumption and supply, with potential to continue limited off-grid operation (island mode). This can improve the resilience of the energy system in face network disturbance due to climate impact |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | 1 | The SRI demand a central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the TBS system in face network disturbance due climate impact(Barrelas et al, 2021) |
| Human wellbeing and organization | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | 1 | This can improve the resilience of the TBS system in face network disturbance due climate impact |

Table 1.2. Rating of the SRI adaptation requirements to the climate change hazard of heavy precipitation

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard heavy precipitation  | Comments  |
| SRI Indicator | Rating  |  |
| Structures | DE-1 Window solar shading control | 1 | Predictive blind control (e.g. based on weather forecast). This can spare the blinds from getting damaged  |
| DE-4 Reporting information regarding performance of dynamic building envelope systems | Position of each product, fault detection, predictive maintenance, real-time & historical sensor data (wind, lux, temperature…). This can improve the reliability of the system and resilience against adverse climate impacts |
| Water, wastewater, and sanitation systems | DHW-3 Report information regarding domestic hot water performance | 1 | The SRI includes the requirement of Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection, nevertheless it is limited to hot water supply and not wastewater and freshwater  |
| MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | Central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the water and sanitation systems in face network disturbance due climate impact(Barrelas et al, 2021) |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | H-1c Storage and shifting of thermal energy | 2 | The SRI includes the requirement of HW storage vessels controlled based on external signals (from BACS or grid), which can serve domestic need in case of network disturbances  |
| H-1f Thermal Energy Storage (TES) for building heating (excluding TABS) | The SRI includes the requirement of Heat storage capable of flexible control through grid signals (e.g. DSM), which can server domestic need in case of network disturbances |
| H-4 Flexibility and grid interaction | The SRI includes the requirement of optimized control of heating system based on local predictions and grid signals (e.g. through model predictive control), which can prepare the system in advance and warn of adverse climate impact  |
| H-3 Report information regarding heating system performance | The SRI includes the requirement of Central or remote reporting of performance evaluation including forecasting and predictive management and fault detection. This can improve the resilience of the heating system in fact of climate change adverse impact  |
| C-1g control of Thermal Energy Storage (TES) operation | Cold storage capable of flexible control through grid signals (e.g. DSM). This can improve the resilience of the cooling system in face network disturbance  |
| C-3 Report information regarding cooling system performance | Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection. This can improve the resilience of the cooling system in fact of climate change adverse impact |
| C-4 Flexibility and grid interaction | Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control). This can improve the resilience of the energy system in face network disturbance  |
| E-3 Storage of (locally generated) electricity | On site storage of energy (e.g. electric battery or thermal storage) with controller optimizing the use of locally generated electricity and possibility to feed back into the grid. This can improve the resilience of the energy system in face network disturbance due climate impact |
| E-2 Reporting information regarding local electricity generation | Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection. This can improve the resilience of the energy system in face network disturbance due climate impact |
| E-8 Support of(micro)grid operation modes | Automated management of (building-level) electricity consumption and supply, with potential to continue limited off-grid operation (island mode). This can improve the resilience of the energy system in face network disturbance due climate impact |
|  | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | Central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the energy system in face network disturbance due climate impact |
| Transportation and mobility  | -  | 0 |  |
| Communication systems  | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | 1 | Central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the energy system in face network disturbance due climate impact |
| Human wellbeing and organization | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | 1 | An advanced central automatic control system with fault detection and diagnosing capabilities can help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |

Table 1.3. Rating of the SRI adaptation requirements to the climate change hazard of wind and storm

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard wind and storm | Comments  |
| SRI Indicator  | Rating  |  |
| Structures | DE-1 Window solar shading control | 1 | Predictive blind control (e.g. based on weather forecast). This can spare the blinds from getting damaged  |
| DE-4 Reporting information regarding performance of dynamic building envelope systems | Position of each product, fault detection, predictive maintenance, real-time & historical sensor data (wind, lux, temperature…). This can improve the reliability of the system and resilience against adverse climate impacts |
| Water, wastewater, and sanitation systems | DHW-3 Report information regarding domestic hot water performance | 1 | The SRI include the requirement of Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection nevertheless its limited to hot water supply and not wastewater and freshwater  |
|  | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the sanitation system in face network disturbance due climate impact |
| Green and blue infrastructure | - | 0 |   |
| Energy systems | H-1c Storage and shifting of thermal energy | 3 | The SRI includes the requirement of HW storage vessels controlled based on external signals (from BACS or grid), which can serve domestic need in case of network disturbances  |
| H-1f Thermal Energy Storage (TES) for building heating (excluding TABS) | The SRI includes the requirement of Heat storage capable of flexible control through grid signals (e.g. DSM), which can serve domestic need in case of network disturbances |
| H-4 Flexibility and grid interaction | The SRI includes the requirement of optimized control of heating system based on local predictions and grid signals (e.g. through model predictive control), which can prepare the system in advance warning of adverse climate impact  |
| H-3 Report information regarding heating system performance | The SRI includes the requirement of Central or remote reporting of performance evaluation including forecasting and predictive management and fault detection. This can improve the resilience of the heating system in fact of climate change adverse impact  |
| C-1g control of Thermal Energy Storage (TES) operation | Cold storage capable of flexible control through grid signals (e.g. DSM). This can improve the resilience of the cooling system in face network disturbance  |
| C-3 Report information regarding cooling system performance | Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection. This can improve the resilience of the cooling system in fact of climate change adverse impact |
| C-4 Flexibility and grid interaction | Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control). This can improve the resilience of the energy system in face network disturbance  |
| E-3 Storage of (locally generated) electricity | On site storage of energy (e.g. electric battery or thermal storage) with controller optimizing the use of locally generated electricity and possibility to feed back into the grid. This can improve the resilience of the energy system in face network disturbance due climate impact |
| E-2 Reporting information regarding local electricity generation | Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection. This can improve the resilience of the energy system in face network disturbance due climate impact |
| E-8 Support of(micro)grid operation modes | Automated management of (building-level) electricity consumption and supply, with potential to continue limited off-grid operation (island mode). This can improve the resilience of the energy system in face network disturbance due climate impact |
| H-1c Storage and shifting of thermal energy | The SRI include the requirement of HW storage vessels controlled based on external signals (from BACS or grid), which can server domestic need in case of network disturbances  |
| H-1f Thermal Energy Storage (TES) for building heating (excluding TABS) | The SRI include the requirement of Heat storage capable of flexible control through grid signals (e.g. DSM), which can serve domestic need in case of network disturbances |
|  | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | 1 | central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the energy system in face network disturbance due climate impact |
| Transportation and mobility  |  - | 0 |  |
| Communication systems  | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | 1 | Central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the technical system in face network disturbance due climate impact |
| Human wellbeing and organization | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | 1 | An advanced central automatic control system with fault detection and diagnosing capabilities can help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |

Table 1.4. Rating of the SRI adaptation requirements to the climate change hazard of drought

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of drought  | Comments  |
| SRI Indicator  | Rating  |  |
| Structures | - | 0 | Drought can increase the risk of soil settling damage (Lariu et al, 2021) |
| Water, wastewater, and sanitation systems | - | 0 |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | - | n/a | There is no direct risk at the energy sector of the building from the drought  |
| Transportation and mobility  | - | n/a | There is no direct risk at the transport sector of the building from the drought  |
| Communication systems  | - | n/a | There is no direct risk at the communication sector of the building from the drought  |
| Human wellbeing and organization | - | 0 |  |

Table 1.5. Rating of the SRI adaptation requirements to the climate change hazard of warming trend and heatwaves

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of warming trend and heatwaves  | Comments  |
| SRI Indicator  | Rating  |  |
| Structures | DE-1 Window solar shading control | 1 | Predictive blind control (e.g. based on weather forecast). This can improve the building climatic performance  |
| DE-4 Reporting information regarding performance of dynamic building envelope systems | Position of each product, fault detection, predictive maintenance, real-time & historical sensor data (wind, lux, temperature…). This can improve the reliability of the system and resilience against adverse climate impacts |
| DE-2 Window open/closed control, combined with HVAC system | The SRI requires an automated mechanical window opening based on room sensor data. In addition to Centralized coordination of operable windows, e.g., to control free natural night cooling. This can reduce the risk of overheating.  |
| Water, wastewater, and sanitation systems | - | n/a | There is no direct risk at the water and wastewater sector of the building from the heatwaves  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | V-3 Free cooling with mechanical ventilation system |  | This can reduce the load on the grid and energy consumption, hence improving the reliability  |
| C-2a Generator control for cooling | This can reduce the load on the grid and energy consumption, hence improving the reliability |
| C-1g Control of Thermal Energy Storage (TES) operation | This can reduce the load on the grid and energy consumption, hence improving the reliability |
| C-4 Flexibility and grid interaction | Optimized control of cooling system based on local predictions and grid signals (e.g. through model predictive control). This can improve the resilience of the energy system in face network disturbance  |
| E-4 Optimizing self-consumption of locally generated electricity | Automated management of local electricity consumption based on current and predicted energy needs and renewable energy availability.  |
| E-3 Storage of (locally generated) electricity | On site storage of energy (e.g. electric battery or thermal storage) with controller optimizing the use of locally generated electricity and possibility to feed back into the grid. This can improve the resilience of the energy system in face network disturbance due climate impact |
| E-2 Reporting information regarding local electricity generation | Performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection. This can improve the resilience of the energy system in face network disturbance due climate impact |
| E-8 Support of(micro)grid operation modes | Automated management of (building-level) electricity consumption and supply, with potential to continue limited off-grid operation (island mode). This can improve the resilience of the energy system in face network disturbance due climate impact |
| MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | central indication of detected faults and alarms for all relevant TBS, including diagnosing functions. This can improve the resilience of the energy system in face network disturbance due climate impact |
| C-3 Report information regarding cooling system performance | Central or remote reporting of performance evaluation including forecasting and/or benchmarking; also including predictive management and fault detection. This can improve the resilience of the cooling system in fact of climate change adverse impact |
| Transportation and mobility  | - | n/a | There is no direct risk at the transport sector of the building from the heatwaves  |
| Communication systems  | MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | 1 | electronic components are susceptible to overheating and an increase in temperature can result in a reduced lifespan and cascading failure (Lakshminarayanan & Sriraam, 2014; Xing, 2020). |
| Human wellbeing and organization |  V-2c Heat recovery control: prevention of overheating" | 1 |  |
| C-1b Emission control for TABS (cooling mode) | This type of advanced control system can help to improve the energy efficiency and comfort of a building, while also reducing the cost of cooling. Using an intermittent operation and room temperature feedback control system can also help to improve the overall sustainability of the building. |
| MC-4 Detecting faults of technical building systems and providing support to the diagnosis of these faults | An advanced central automatic control system with fault detection and diagnosing capabilities can help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |

# 2 Assessing the Inclusion Climate Change Adaptation Measures in the Performance Requirements of in The SmartScore Label

Table 2.1. Rating of the SmartScore adaptation requirements to the climate change hazard of flooding, flash floods and groundwater rise

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard flooding, flash floods and groundwater rise | Comments  |
| SmartScore Indicator  | Rating  |  |
| Structures | TF2:5Asset information model | 1 | A BIM model of the building can reduce the building vulnerability in the pre disaster and post disaster phases and reduce the down time in an event of exposures to climate hazard(Sertyesilisik, 2017)  |
| Water, wastewater, and sanitation systems | UF5:6 Predictive maintenance | 0 | When the building's systems are able to predict when a piece of equipment might fail this helps maintenance work to be performed before faults occur which increase the resilience of the building systems (Barrelas et al, 2021). However, this remain limited to the active part of the system and not its passive elements |
| UF5:3System alarms | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building. However, this remain limited to the active part of the system and not its passive elements  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | UF5:3System alarms | 1 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| UF5:6 Predictive maintenance | When the building's systems are able to predict when a piece of equipment might fail this helps maintenance work to be performed before faults occur(Barrelas et al, 2021) |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | UF5:3System alarms | 2 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| TF1:1Physical diversity of tenant connectivity routes | The indicator demands that smart workplace solutions can be enabled via a resilient and reliable internet connection protected from single points of failure. The physical separation can protect against a variety of external factors, such as fire, flooding. Moreover, it can also help to reduce the risk of cascading failures, where the failure of one infrastructure component triggers a series of failures in other components |
| TF3:1Network infrastructure | The indicator aims to ensure that the critical components for the distribution of smart building capabilities are located in the best possible environment for their stable and ongoing operation. a reliable, resilient, and secure network that allows the efficient monitoring and control of all edge devices and connected systems.  |
| TF3:4Wireless networks | The indicator aims to ensure that reliable, resilient and secure networks is in place. This allows the efficient monitoring and control of all relevant IoT and edge devices |
| Human wellbeing and organization | UF5:3System alarms | 2 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
|  | UF6:4Emergency alerts | Building users can react to a potential security and health risks in the building and surrounding area. This can help the users taking protective measures(Kitazawa & Hale, 2021) |

Table 2.2 Rating of the SmartScore adaptation requirements to the climate change hazard of heavy precipitation

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of heavy precipitation  | Comments  |
| SmartScore Indicator  | Rating  |  |
| Structures | TF2:5Asset information model | 1 | A BIM model of the building can reduce the building vulnerability in the pre disaster and post disaster phases and reduce the down time in an event of exposures to climate hazard (Bouwman et al)  |
| Water, wastewater, and sanitation systems | UF5:6 Predictive maintenance | 0 | When the building's systems can predict when a piece of equipment might fail this helps maintenance work to be performed before faults occur which increase the resilience of the building systems (Cologna & Siegrist). However, this remains limited to the active part of the system and not its passive elements. |
| UF5:3System alarms | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building. However, this remain limited to the active part of the system and not its passive elements |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | UF5:3System alarms | 1 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| UF5:6 Predictive maintenance | When the building's systems are able to predict when a piece of equipment might fail this helps maintenance work to be performed before faults occur |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | UF5:3System alarms | 1 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| TF1:1Physical diversity of tenant connectivity routes | The indicator demands that smart workplace solutions can be enabled via a resilient and reliable internet connection protected from single points of failure. The physical separation can protect against a variety of external factor and can also help to reduce the risk of cascading failures, where the failure of one infrastructure component triggers a series of failures in other components |
| TF3:1Network infrastructure | the indicator aims to ensure that the critical components for the distribution of smart building capabilities are located in the best possible environment for their stable and ongoing operation. a reliable, resilient, and secure network that allows the efficient monitoring and control of all edge devices and connected systems.  |
| TF3:4Wireless networks | The indicator aims to ensure that reliable, resilient and secure networks is in place. This allows the efficient monitoring and control of all relevant IoT and edge devices |
| Human wellbeing and organization | UF5:3System alarms | 1 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| UF6:4Emergency alerts | Building users can react to a potential security and health risks in the building and surrounding area. This can help the users taking protective measures(Kitazawa & Hale, 2021) |

Table 2.3. Rating of the SmartScore adaptation requirements to the climate change hazard of storm and wind hazard

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of storm and wind hazard | Comments  |
| SmartScore Indicator  | Rating  |  |
| Structures | TF2:5Asset information model | 1 | A BIM model of the building can reduce the building vulnerability in the pre disaster and post disaster phases and reduce the down time in an event of exposures to climate hazard(Sertyesilisik, 2017).  |
| Water, wastewater, and sanitation systems | UF5:6 Predictive maintenance | 1 | When the building's systems can predict when a piece of equipment might fail this helps maintenance work to be performed before faults occur which increase the resilience of the building systems (Cologna & Siegrist). However, this remains limited to the active part of the system and not its passive elements |
| UF5:3System alarms | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building. However, this remains limited to the active part of the system and not its passive elements |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | UF5:3System alarms | 1 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| UF5:6 Predictive maintenance | When the building's systems are able to predict when a piece of equipment might fail this helps maintenance work to be performed before faults occur |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | UF5:3System alarms | 1 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| TF1:1Physical diversity of tenant connectivity routes | The indicator demands a resilient and reliable internet connection protected from single points of failure. The physical separation can protect against a variety of external factor and can also help to reduce the risk of cascading failures, where the failure of one infrastructure component triggers a series of failures in other components |
| TF3:1Network infrastructure | The indicator aims to ensure that the critical components for the distribution of smart building capabilities are located in the best possible environment for their stable and ongoing operation. a reliable, resilient, and secure network that allows the efficient monitoring and control of all edge devices and connected systems.  |
| TF3:4Wireless networks | The indicator aims to ensure that reliable, resilient and secure networks is in place. This allows the efficient monitoring and control of all relevant IoT and edge devices |
| Human wellbeing and organization | UF5:3System alarms | 1 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| UF6:4Emergency alerts | Building users can react to a potential security and health risks in the building and surrounding area |

Table 2.4. Rating of the SmartScore adaptation requirements to the climate change hazard of drought

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of drought  | Comments  |
| SmartScore Indicator  | Rating  |  |
| Structures | TF2:5Asset information model | 1 | Drought can increase the risk of soil settling damage (Lariu et al, 2021), A BIM model of the building can reduce the building vulnerability in the pre disaster and post disaster phases and reduce the down time in an event of exposures to climate hazard(Bouwman et al)  |
| Water, wastewater, and sanitation systems | UF3:3Water reporting | 1 | Solution to track the building's water consumption in real time can help reduce consumption  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | - | n/a | There is no direct risk at the energy sector of the building from the drought  |
| Transportation and mobility  | - | n/a | There is no direct risk at the transport sector of the building from the drought  |
| Communication systems  | - | n/a | There is no direct risk at the communication sector of the building from the drought  |
| Human wellbeing and organization | UF3:3Water reporting | 1 | Users can receive early warnings of problems with the water supply |
| UF6:4Emergency alerts | Building users can react to a potential drought alert (Kitazawa & Hale, 2021)  |

Table 2.5. Rating of the SmartScore adaptation requirements to the climate change hazard of warming trend and heatwaves

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of warming trend and heatwaves  | Comments  |
| SmartScore Indicator  | Rating  |  |
| Structures | TF2:5Asset information model | 1 | A BIM model of the building can reduce the building vulnerability in the pre disaster and post disaster phases and reduce the down time in an event of exposures to climate hazard (Bouwman et al).  |
| Water, wastewater, and sanitation systems | - | n/a | There is no direct risk at the water and wastewater sector of the building from the heatwaves  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | UF5:3System alarms | 1 | The indicator demands the users to be alerted in real time when a building system fails. This help building operators to quickly identify and resolve issues with TBS, minimize downtime, and ensure the safe and efficient operation of the building |
| Transportation and mobility  | - | n/a | There is no direct risk at the transport sector of the building from the heatwaves  |
| Communication systems  | UF5:3System alarms | 1 | electronic components are susceptible to overheating and an increase in temperature can result in a reduced lifespan and cascading failure (Lakshminarayanan & Sriraam, 2014; Xing, 2020). |
| Human wellbeing and organization | UF2:3Wellbeing reporting | 1 | The indicator asks to provide the user and operator with a solution to track and report on the building's wellbeing key performance indicators in real-time |
| UF2:5Comfort optimization | The indicator asks to provide the user and with a solution to optimize comfort conditions in common spaces |

# Assessing the Inclusion Climate Change Adaptation Measures in the Performance Requirements of The WiredScore Label

Table 3.1. Rating of the WiredScore adaptation requirements to the climate change hazard of flooding, flash floods and groundwater rise

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard flooding, flash floods and groundwater rise | Comments  |
| WiredScore Indicator  | Rating  |  |
| Structures | 0 | 0 |  |
| Water, wastewater, and sanitation systems | - | 0 |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | E2Tenant backup power | 1 | Provision of designated space to tenants and service providers, for the placement of private generator / backup power can increase the resilience of the power system and reduce downtime  |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | A1 In-building mobile performance | 3 | A reliable reception of mobile can help ensure that emergency alert text messages are received  |
| A3Backbone cabling | Provision of building-owned backbone cabling for the distribution of systems and services throughout the building can increase the resilience of the communication system and reduce down time  |
| A5 Riser in-building technology equipment space | The extra space can increase the resilience of the communication system and reduce down time |
| B1 Building Infrastructure - Points of Entry | WiredScore requires the use of underground pathways. This can reduce the risk of network disruption in case of climate change related event. |
| B2 Points of entry diversity | Single point of entry are vulnerable to failure. The physical separation can protect against a variety of external factor and can also help to reduce the risk of cascading failures, where the failure of one infrastructure component triggers a series of failures in other components |
| C4 Leak / flood protection for telecommunications room | The indicator demands that telecommunications room is set above the floodplain level local to the room, and protection measures are in place against internal leaks / flooding |
| D3 Riser diversity | connectivity services are susceptible to disruption in the vertical service routes by factors such as in-building construction work, maintenance, fire, and flooding. Riser diversity provides a physical separation of incoming services at the riser level, which improves the resiliency of business-critical service.  |
| E1 Telecommunications equipment backup power | Provision of a building backup power source with capabilities to supply emergency power can protect telecommunications feeds / equipment from power failures due to either mains network outages or damage caused by extreme weather events |
| Human wellbeing and organization | A1 In-building mobile performance | 1 | A reliable reception of mobile signals can help ensure that emergency alert text messages are received. This can help the users taking protective measures(Kitazawa & Hale, 2021) |

Table 3.2. Rating of the WiredScore adaptation requirements to the climate change hazard of hazard heavy precipitation

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard heavy precipitation | Comments  |
| WiredScore Indicator  | Rating  |  |
| Structures | 0 | 0 |  |
| Water, wastewater, and sanitation systems |  |  |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | E2Tenant backup power | 1 | Provision of designated space to tenants and service providers, for the placement of private generator / backup power can increase the resilience of the power system and reduce downtime  |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | A1 In-building mobile performance | 3 | A reliable reception of mobile can help ensure that emergency alert text messages are received  |
| A3Backbone cabling | Provision of building-owned backbone cabling for the distribution of systems and services throughout the building can increase the resilience of the communication system and reduce down time  |
| A5 Riser in-building technology equipment space | The extra space can increase the resilience of the communication system and reduce down time |
| B1 Building Infrastructure - Points of Entry | WiredScore requires the use of underground pathways. This can reduce the risk of network disruption in case of climate change related event. |
| B2 Points of entry diversity | Single point of entry are vulnerable to failure. The physical separation can protect against a variety of external factor and can also help to reduce the risk of cascading failures, where the failure of one infrastructure component triggers a series of failures in other components |
| D3 Riser diversity | Connectivity services are susceptible to disruption in the vertical service routes by factors such as in-building construction work, maintenance, fire, and flooding. Riser diversity provides a physical separation of incoming services at the riser level, which improves the resiliency of business-critical service.  |
| E1 Telecommunications equipment backup power | Provision of a building backup power source with capabilities to supply emergency power can protect telecommunications feeds / equipment from power failures due to either mains network outages or damage caused by extreme weather events |
| Human wellbeing and organization  | A1 In-building mobile performance | 1 | A reliable reception of mobile signals can help ensure that emergency alert text messages are received . This can help the users taking protective measures(Kitazawa & Hale, 2021) |

Table 3.3. Rating of the WiredScore adaptation requirements to the climate change hazard of storm and wind hazard

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of storm and wind hazard | Comments  |
| WiredScore Indicator  | Rating  |  |
| Structures | 0 | 0 |  |
| Water, wastewater, and sanitation systems |  |  |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | E2Tenant backup power | 1 | Provision of designated space to tenants and service providers, for the placement of private generator / backup power can increase the resilience of the power system and reduce downtime  |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | A1 In-building mobile performance | 3 | A reliable reception of mobile can help ensure that emergency alert text messages are received  |
| A3Backbone cabling | Provision of building-owned backbone cabling for the distribution of systems and services throughout the building can increase the resilience of the communication system and reduce down time  |
| A5 Riser in-building technology equipment space | The extra space can increase the resilience of the communication system and reduce down time |
| BBuilding Infrastructure - Points of Entry | WiredScore requires the use of underground pathways. This can reduce the risk of network disruption in case of climate change related event. |
| B2Points of entry diversity | Single point of entry are vulnerable to failure. The physical separation can protect against a variety of external factor and can also help to reduce the risk of cascading failures, where the failure of one infrastructure component triggers a series of failures in other components |
| D3 Riser diversity | Connectivity services are susceptible to disruption in the vertical service routes by factors such as in-building construction work, maintenance, fire, and flooding. Riser diversity provides a physical separation of incoming services at the riser level, which improves the resiliency of business-critical service.  |
| E1 Telecommunications equipment backup power | Provision of a building backup power source with capabilities to supply emergency power can protect telecommunications feeds / equipment from power failures due to either mains network outages or damage caused by extreme weather events |
| Human wellbeing and organization | A1 In-building mobile performance | 1 | A reliable reception of mobile signals can help ensure that emergency alert text messages are received. This can help the users taking protective measures(Kitazawa & Hale, 2021) |

Table 3.4. Rating of the WiredScore adaptation requirements to the climate change hazard of drought.

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of drought  | Comments  |
| WiredScore Indicator  | Rating  |  |
| Structures | - | 0 | Drought can increase the risk of soil settling damage (Lariu et al, 2021) |
| Water, wastewater, and sanitation systems | - | 0 |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | - | n/a | There is no direct risk at the energy sector of the building from the drought  |
| Transportation and mobility  | - | n/a | There is no direct risk at the transport sector of the building from the drought  |
| Communication systems  | - | n/a | There is no direct risk at the communication sector of the building from the drought  |
| Human wellbeing and organization  | A1 In-building mobile performance | 1 | A reliable reception of mobile signals can help ensure that emergency alert text messages are received  |

Table 3.5. Rating of the WiredScore adaptation requirements to the climate change hazard of warming trend and heatwave

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of warming trend and heatwave | Comments  |
| WiredScore Indicator  | Rating  |  |
| Structures | - | 0 |  |
| Water, wastewater, and sanitation systems | - | n/a | There is no direct risk at the water and wastewater sector of the building from the heatwaves  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | E2Tenant backup power | 1 | Provision of designated space to tenants and service providers, for the placement of private generator / backup power can increase the resilience of the power system and reduce downtime  |
| Transportation and mobility  | - | n/a | There is no direct risk at the transport sector of the building from the heatwaves  |
| Communication systems  | E1 Telecommunications equipment backup power | 3 | Provision of a building backup power source with capabilities to supply emergency power can protect telecommunications feeds / equipment from power failures due to either mains network outages or damage caused by extreme weather events |
| C5 Climate control in telecommunications room | The indicator demands that climate control in a telecommunications room is provided by active air conditioning or mechanically forced ventilation |
| A1 In-building mobile performance | A reliable reception of mobile can help ensure that emergency alert text messages are received  |
| A3Backbone cabling | Provision of building-owned backbone cabling for the distribution of systems and services throughout the building can increase the resilience of the communication system and reduce down time  |
| A5 Riser in-building technology equipment space | The extra space can increase the resilience of the communication system and reduce down time |
| Human wellbeing and organization | A1 In-building mobile performance | 1 | A reliable reception of mobile signals can help ensure that emergency alert text messages are received. This can help the users taking protective measures(Kitazawa & Hale, 2021) |

# Assessing the Inclusion Climate Change Adaptation Measures in the Performance Requirements of The R2S Label

Table 4.1. Rating of the R2S adaptation requirements to the climate change hazard of flooding, flash floods and groundwater rise

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard flooding, flash floods and groundwater rise | Comments  |
| R2S indicator  | Rating  |  |
| Structures | 0 | 0 |  |
| Water, wastewater, and sanitation systems | - | 0 |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems |  | 0 |  |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | CO5.1 Building wiring redundancy capability | 2 | The indicator demands a prevention of single point of failure. This increases the system resilience and reduce downtime  |
| RE2.1 Building Smart Network Resilience Capacity | The R2S requires that the Smart Network supports network failure detection and self-healing mechanism. This can reduce downtime and improve the resilience of the system  |
| CO1.2 Redundancy of connection of the building to any type of external wired link | The R2S demands provision for redundant internal routing of external operator links. This increases the system resilience and reduce downtime. |
| IN2.2 Integration into the digital model (BIM) | The indicator requires that the digital model (BIM) integrates information about the location and state of equipment and sensors of the network  |
| CO5.2 Infrastructure power supply | The indicator demands to guarantee the continuity of Smart Network services, in the event of an indefinite power outage This increase the system resilience to climate impact |
| Human wellbeing and organization  | CO3.1 Nature and quality of wireless networks | 1 | The R2S requires that the building has adequate coverage inside its various spaces, for the main radio networks (GSM, Wi-Fi, etc.). A reliable reception of mobile and Wi-Fi signals can help ensure that emergency alert text messages are received. This can help the users taking protective measures(Kitazawa & Hale, 2021) |

Table 4.2. Rating of the R2S adaptation requirements to the climate change hazard of heavy precipitation

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard heavy precipitation  | Comments  |
| R2S indicator  | Rating  |  |
| Structures | 0 | 0 |  |
| Water, wastewater, and sanitation systems | - | 0 |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems |  | 0 |  |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | CO5.1 Building wiring redundancy capability | 2 | The indicator demands a prevention of single point of failure. This increases the system resilience and reduce downtime  |
| RE2.1 Building Smart Network Resilience Capacity | The R2S requires that the Smart Network supports network failure detection and self-healing mechanism. This can reduce downtime and improve the resilience of the system  |
| CO1.2 Redundancy of connection of the building to any type of external wired link | The R2S demands provision for redundant internal routing of external operator links. This increases the system resilience and reduce downtime. |
| IN2.2 Integration into the digital model (BIM) | The indicator requires that the digital model (BIM) integrates information about the location and state of equipment and sensors of the network. |
| CO5.2 Infrastructure power supply | The indicator demands to guarantee the continuity of Smart Network services, in the event of an indefinite power outage This increase the system resilience to climate impact |
| Human wellbeing and organization | CO3.1 Nature and quality of wireless networks | 1 | The R2S requires that the building has adequate coverage inside its various spaces, for the main radio networks (GSM, Wi-Fi, etc.). A reliable reception of mobile and Wi-Fi signals can help ensure that emergency alert text messages are received. This can help the users taking protective measures(Kitazawa & Hale, 2021) |

Table 4.3. Rating of the R2S adaptation requirements to the climate change hazard of storm and wind

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of storm and wind  | Comments  |
| R2S indicator  | Rating  |  |
| Structures | - | 0 |  |
| Water, wastewater, and sanitation systems | - | 0 |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems |  | 0 |  |
| Transportation and mobility  | - | 0 |  |
| Communication systems  | CO5.1 Building wiring redundancy capability | 2 | The indicator demands a prevention of single point of failure. This increases the system resilience and reduce downtime  |
| RE2.1 Building Smart Network Resilience Capacity | The R2S requires that the Smart Network supports network failure detection and self-healing mechanism. This can reduce downtime and improve the resilience of the system  |
| CO1.2 Redundancy of connection of the building to any type of external wired link | The R2S demands provision for redundant internal routing of external operator links. This increases the system resilience and reduce downtime |
| IN2.2 Integration into the digital model (BIM) | The indicator requires that the digital model (BIM) integrates information about the location and state of equipment and sensors of the network  |
| CO5.2 Infrastructure power supply | The indicator demands to guarantee the continuity of Smart Network services, in the event of an indefinite power outage This increase the system resilience to climate impact |
| Human wellbeing and organization | CO3.1 Nature and quality of wireless networks | 1 | The R2S requires that the building has adequate coverage inside its various spaces, for the main radio networks (GSM, Wi-Fi, etc.). A reliable reception of mobile and Wi-Fi signals can help ensure that emergency alert text messages are received. This can help the users taking protective measures(Kitazawa & Hale, 2021)  |

Table 4.4. Rating of the R2S adaptation requirements to the climate change hazard of drought

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of drought  | Comments  |
| R2S Indicator  | Rating  |  |
| Structures | - | 0 | Drought can increase the risk of soil settling damage (Lariu et al, 2021) |
| Water, wastewater, and sanitation systems | - | 0 |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems | - | n/a | There is no direct risk at the energy sector of the building from the drought  |
| Transportation and mobility  | - | n/a | There is no direct risk at the transport sector of the building from the drought  |
| Communication systems  | - | n/a | There is no direct risk at the communication sector of the building from the drought  |
| Human wellbeing and organization | CO3.1 Nature and quality of wireless networks | 1 | The R2S requires that the building has adequate coverage inside its various spaces, for the main radio networks (GSM, Wi-Fi, etc.). A reliable reception of mobile and Wi-Fi signals can help ensure that emergency alert text messages are received. This can help the users taking protective measures(Kitazawa & Hale, 2021)  |

Table 4.5. Rating of the R2S adaptation requirements to the climate change hazard of warming trend and heatwave

|  |  |  |
| --- | --- | --- |
| Selected Key Urban sector as defined by the IPCC (Revi et al, 2017) | Performance requirements and Rating systems for the climate hazard of warming trend and heatwave | Comments  |
| R2S indicator  | Rating  |  |
| Structures | - | 0 |  |
| Water, wastewater, and sanitation systems | - | n/a |  |
| Green and blue infrastructure | - | 0 |  |
| Energy systems |  | 0 |  |
| Transportation and mobility  | - | n/a |  |
| Communication systems  | RE2.1 Building Smart Network Resilience Capacity | 2 | The R2S requires that the Smart Network supports network failure detection and self-healing mechanism. This can reduce downtime and improve the resilience of the system  |
| IN2.2 Integration into the digital model (BIM) | The indicator requires that the digital model (BIM) integrates information about the location and state of equipment and sensors of the network  |
| CO5.2 Infrastructure power supply | The indicator demand to guarantee the continuity of Smart Network services, in the event of an indefinite power outage. This increases the system resilience to climate impact |
| Human wellbeing and organization  | CO3.1 Nature and quality of wireless networks | 1 | The R2S requires that the building has adequate coverage inside its various spaces, for the main radio networks (GSM, Wi-Fi, etc.). A reliable reception of mobile and Wi-Fi signals can help ensure that emergency alert text messages are received. This can help the users taking protective measures (Kitazawa & Hale, 2021)  |

# References

Barrelas, J., Ren, Q. & Pereira, C. (2021) Implications of climate change in the implementation of maintenance planning and use of building inspection systems. *Journal of Building Engineering*, 40, 102777.

Bouwman, H., Nikou, S., Molina-Castillo Francisco, J. & de Reuver, M. (2018) The impact of digitalization on business models. *Digital Policy, Regulation and Governance*, 20(2), 105-124.

Cologna, V. & Siegrist, M. (2020) The role of trust for climate change mitigation and adaptation behaviour: A meta-analysis. *Journal of Environmental Psychology*, 69, 101428.

Kitazawa, K. & Hale, S. A. (2021) Social media and early warning systems for natural disasters: A case study of Typhoon Etau in Japan. *International Journal of Disaster Risk Reduction*, 52, 101926.

Lakshminarayanan, V. & Sriraam, N. (2014) The effect of temperature on the reliability of electronic components, *2014 IEEE international conference on electronics, computing and communication technologies (CONECCT)*. IEEE.

Lariu, P., Schwarzak, S., Eichstädt, R., Wifling, M., Joneck, M. & Verbraucherschutz, B. B. S. f. U. u. (2021) *Klimaanpassung in Bayern: Handbuch zur Umsetzung*Bayerisches Staatsministerium für Umwelt und Verbraucherschutz (StMUV).

Revi, A., Satterthwaite, D. E., Aragón-Durand, F., Corfee-Morlot, J., Kiunsi, R. B., Pelling, M., Roberts, D. C., Solecki, W., Field, C. & Barros, V. (2017) Urban Areas in Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part A: Global and Sectoral Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change.

Sertyesilisik, B. (2017) Building Information Modeling as Tool for Enhancing Disaster Resilience of the Construction Industry.

Xing, L. (2020) Cascading failures in internet of things: review and perspectives on reliability and resilience. *IEEE Internet of Things Journal*, 8(1), 44-64.