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Comprehensive Resilience Assessment System: Towards Climate-Resilient and Sustainable Primary Healthcare Facilities in South-East Asia

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Abstract

As the climate crisis continues with more extreme weather events increasing the risks to people's health, healthcare systems, and facilities, it is becoming more urgent to address the climate resilience and environmental sustainability of primary healthcare facilities. This paper presents an international multidisciplinary summer school jointly organized by Thammasat University (Thailand), KU Leuven Faculty of Architecture (Belgium), in collaboration with World Health Organization (WHO) Téchne and WHO Country Office for Thailand, with the participation of partner universities from South-East Asia, to examine these issues and develop solutions. We outline the development of a Comprehensive Resilience Assessment System (CRAS), an academic draft of an integrated assessment tool of primary healthcare centers in terms of climate resilience and environmental sustainability, which includes the evaluation of energy, water supply and treatment, structural and non-structural safety, and hazardous waste disposal management in suburban and rural settings in South-East Asia. The CRAS will be submitted to WHO for endorsement and implementation as part of its efforts to support national governments in providing a primary healthcare system that is climate resilient and sustainable in the face of infectious disease outbreaks and/or natural hazards. Taking a systems thinking and a whole-of-society approach this paper outlines the specificities of primary healthcare centers and their role in an increasingly warmer climate, the summer school research methodology in terms of literature reviewed, preliminary data collected, and the novel pedagogical research-by-design process undertaken to produce the Comprehensive Resilience Assessment System online tool as a form of environmental assessment for primary healthcare centers.

Keywords

Primary Healthcare Facilities; Comprehensive Resilience Assessment System; Climate Resilience; Environmental Sustainability; Infection Prevention and Control

1. Introduction

1.1 Climate Change and Healthcare Facilities

July 2023, the 'summer of extremes,' considered the hottest month on record at the time of this writing, was mired by parallel heat waves affecting large parts of North Africa, Europe, Asia, and the United States of America, while extreme typhoons hit parts of the Asia-Pacific region causing major impacts to people's health and the environment (World Meteorological Organization [WMO], 2023). According to the United Nations World Meteorological Organization (WMO) extreme weather is an increasing occurrence in a warming climate and is 'having a major impact on human health, ecosystems, economies, agriculture, energy and water supplies. This underlines the increasing urgency of cutting greenhouse gas emissions as quickly and as deeply as possible' (WMO, 2023).

As highlighted in the United Nations Climate Change conference (COP 28) in 2023, with the ongoing climate crisis bringing about more extreme weather events which are occurring more frequently and with greater intensity, the risks to people's health, health systems, and facilities will increase, thus reducing the capacity of health professionals to protect people from various climate-related hazards (United Nations, 2023). Healthcare facilities are the first and last line of defense in alleviating the impact of climate change as they provide necessary services and care to people affected by extreme weather and other long-term climate hazards. However, healthcare facilities also pose a negative impact on the environment and health, contributing up to four percent of global emissions of greenhouse gases (GHGs) due to energy consumption, exacerbated by the generation and poor management of medical and single-use plastics waste (Andreae, 2025). Hence, there is a clear need for enhancing the capacity to assess the environmental sustainability of healthcare facilities and identify interventions that optimize the consumption of resources (e.g. water, energy, food), reduce emissions of greenhouse gases, and properly manage waste (including biological, chemical, and radiological).

1.2 International Collaboration and Summer Schools

To address this issue, KU Leuven (Belgium), Thammasat University (Thailand), and the World Health Organization's (WHO) Technical Science for Health Network, Téchne, teamed up with the WHO Country Office (WCO) for Thailand and engaged in a knowledge-sharing program of international multidisciplinary summer schools. This collaboration set out to ascertain the interest in and crucial importance of primary healthcare (PHC) facilities which are climate-resilient, environmentally sustainable, and prepared for infectious disease outbreaks and/or natural hazards for a whole-of-society approach.

The general objective of the summer schools is to contribute to Téchne's long-term goal of national and international capacity building through multidisciplinary, community-based, and informed approaches that create safer, healthier, equitable, and more sustainable healthcare systems. The specific objectives are twofold: firstly, to generate a broad-based multidisciplinary regional platform of students and faculty members and engage them in capacity-building modules that will enhance knowledge sharing, international cooperation, and strengthen the WHO-Téchne network in South-East Asia; and secondly, to consolidate existing WHO and other United Nations (UN) guidelines and help draft an online and widely applicable graphical tool for assessing and designing primary healthcare facilities in suburban and rural settings in South-East Asia that can respond to infectious disease outbreaks and/or natural hazards. The summer schools' academic output is meant to complement current literature regarding the performance of large-scale healthcare facilities' indoor

environmental quality, solid waste management, and life cycle sustainability, with a more comprehensive assessment of smaller-scale PHC facilities in terms of climate resilience, environmental sustainability, infection prevention, and safety.

1.3 Summer School 2023

The first of a multi-part summer school, held in July 2023, was organized by a conglomerate of Thammasat University (TU) faculties comprising the Faculty of Architecture and Planning, Sirindhorn International Institute of Technology (SIIT), Faculty of Nursing, and Faculty of Public Health, who co-hosted the event in collaboration with KU Leuven's Faculty of Architecture, WHO Téchne, and the WHO Country Office for Thailand. The organizers then engaged partner universities from South-East Asia including the Institute of Technology of Cambodia (ITC), Paññāsāstra University of Cambodia (PUC), the University of Health Sciences of Lao People's Democratic Republic (UHS), Universitas Trisakti, Indonesia (Usakti), and the University of Architecture Ho Chi Minh City, Viet Nam (UAH).

In preparation for the 2023 summer school, Téchne, as part of its collaboration with the KU Leuven M.Sc. Arch. curriculum, pursued a series of research-and-consultation sessions that produced a 'preliminary checklist' and a comparative spatial usage matrix for PHC facilities. This output formed the basis of the first two-week hybrid phase of the summer school which involved pre-recorded lectures and a PHC facility case study in the respective home countries of the participating universities. Subsequently, the organizers and participants gathered from 16 to 27 July 2023 for an on-site intensive workshop at the Faculty of Architecture and Planning, also known as Thammasat Design School (TDS), Thammasat University, in Thailand.

This on-site component of the summer school sought to address PHC resilience from a wide range of perspectives. It gathered a multidisciplinary group of 32 under- and post-graduate students from Belgium, Cambodia, India, Indonesia, the Republic of Korea, Lao People's Democratic Republic (PDR), Thailand, and Viet Nam, as well as 11 instructors from the organizing institutions and their partner universities. The participants engaged in multidisciplinary collaborative work, where they were grouped and re-grouped to review the case studies of PHC facilities that they had conducted in their respective home countries, systemically revise the checklist used in these case studies, and fine-tune it into an assessment tool. For each of these tasks, students worked closely with the instructors who oversaw the progress and suggested improvements regarding all aspects of the research-by-design process. The working format of the summer school included on-site explorative research and fieldwork, combined with lectures, working sessions, reflection moments, and presentations at TDS, Rangsit Campus.

1.4 Environmental Assessment of Healthcare Facilities

The result of the 2023 summer school was an academic draft of a 'Comprehensive Resilience Assessment System (CRAS)' for primary healthcare facilities, meant to be used as an online tool to assess the performance of healthcare centers in terms of climate resilience, environmental sustainability, infection prevention and control (IPC), and overall safety. This academic draft formed the basis for further scrutiny through theses research, while the August 2024 edition of the international multidisciplinary summer school more fully tested the proposed CRAS through a new round of case studies, fine-tuning and elaborating the assessment framework into a draft detailed design brief for PHC facilities in suburban and rural settings in South-East Asia.

As the climate crisis continues with more extreme weather events increasing the risks for healthcare systems and facilities, this research proposes a novel pedagogical approach and research methodology to examine these issues and develop solutions. By taking a systems thinking and a whole-of-society approach, this research, firstly, provides an outline of the primary healthcare system and facilities and their role in mitigating climate change impacts; secondly, outlines the summer school workshop background; thirdly, explains the research methodology in terms of the teaching-learning activities, literature reviewed, and the development of the assessment method for primary healthcare facilities; and lastly, explains how the Comprehensive Resilience Assessment System online tool works.

2. Study Background

2.1 Primary Healthcare

The United Nations Human Settlement Programme (UN-Habitat) in their 2022 *World Cities Report* describes the need to reduce inequalities in cities and human settlements by providing equitable access to infrastructure and services, particularly healthcare, which is an important factor for an effective response to health crises (United Nations Human Settlements Programme [UN-Habitat], 2022). 'The nature of infectious diseases is such that no one is safe until everyone is safe' (UN-Habitat, 2022, p. 188).

Climate change 'poses the foremost contemporary urban health threat. Climate-related health impacts must be addressed across several sectors and levels, including at the home, workplace, neighbourhood, city, metropolitan and regional scales' (UN-Habitat, 2022, p. 213). To achieve a sustainable urban future in the face of urgent climate related challenges, we need to promote and secure healthcare which is both inclusive and resilient. With the rise of urbanization and the heightened risk of zoonoses, particularly towards the urban-rural fringes, we live in a time 'where one new infectious disease appears in humans every four months' (UN-Habitat, 2022, p. 214). We need to address these complex and integrated challenges by enhancing healthcare preparedness for climate related health risks with solutions which provide climate and health co-benefits.

According to WHO and the United Nations Children's Fund (UNICEF):

> PHC is a whole-of-society approach to health that aims to ensure the highest possible level of health and wellbeing and their equitable distribution by focusing on people´s needs and preferences (as individuals, families, and communities) as early as possible along the continuum from health promotion and disease prevention to treatment, rehabilitation and palliative care, and as close as feasible to people's everyday environment (World Health Organization & United Nations Children's Fund [UNICEF], 2018, p.2).

PHC is the cornerstone of any functional healthcare system as PHC facilities are closest to the community and should be designed to serve those communities in the most effective way. This implies that properly functioning PHC facilities generally should provide medical services, medicines, and other essential services including vaccination, primary diagnosis of infectious diseases, as well as the treatment of chronic diseases. Additionally, PHC facilities should be ready to provide first-line medical services in case of natural hazards as well as to stabilize and transfer patients to more specialized facilities if needed.

‘PHC is the most inclusive, equitable, cost-effective and efficient approach to enhance people’s physical and mental health, as well as social well-being’ (World Health Organization [WHO], 2025). The physical infrastructure of PHC facilities is important as it can impact healthcare providers and their ability to do their jobs as well as the satisfaction of patients, which also affects the use of health services. The needs and maintenance of such infrastructure often are overlooked or neglected particularly in the case of primary healthcare settings including clinics and health centers in suburban and rural settings.

The main spatial requirements for the proper operation of a PHC facility depend on various factors such as the socio-economic context, population coverage, and availability of human resources. Nevertheless, the main spaces/rooms required for the facility include: an entrance hall, examination and consultation rooms, vaccination and sampling room, multipurpose room, as well as support services. Moreover, the key design drivers of a PHC facility include: environmental sustainability and climate resilience, infection prevention and control (IPC), mental health, accessibility, and inclusiveness, as well as user-centered design. In the face of the urgent climate crises and other hazards, PHC facilities should respond to local conditions of exposure and vulnerability, prioritizing context and user experiences, acknowledging communities, culture, as well as the social and historical contexts of their locations. Thus, PHC facilities can encourage collaboration and social interaction within a community, promoting a sense of ownership and belonging.

Despite their crucial importance in the overall healthcare system, PHC facilities have not been thoroughly researched in the healthcare literature. This also could be observed in the sources consulted for compiling the preliminary checklist for the summer school research, including *Checklists to Assess vulnerabilities in Health Care Facilities in the Context of Climate Change* (World Health Organization [WHO], 2021), *Hospital Safety Index: Guide for Evaluators* (World Health Organization [WHO] & Pan American Health Organization [PAHO], 2015), *and Infection Prevention and Control Assessment Framework at the Facility Level* (WHO, 2018). Whilst these publications deal in general terms with the issues of climate resilience, environmental sustainability, infection prevention and control, and overall safety, they do not address the specific scale and scope of PHC facilities.

To distinguish PHC from secondary and tertiary healthcare, primary healthcare includes everyday healthcare for the community, provided by general practitioners (GPs) and nurses, and is the first point of contact for patients with non-emergency situations. Secondary healthcare is health services provided by medical specialists, referred from the primary healthcare provider while tertiary healthcare is for specialized or extended care involving complex and advanced equipment, treatment, or surgeries, typically provided at a hospital or health center. Thus, PHC facilities are different in scale and scope to secondary or tertiary healthcare, which are by necessity larger clinics or provincial hospitals, and the current WHO checklists and guidelines are not specifically designed to address smaller scale PHC facilities in suburban and rural settings.

The summer school program outlined in this study seeks to compensate for the voids in existing literature by highlighting PHC facilities and, more specifically, by adopting the location- and climate-specific perspective of flood-prone suburban and rural areas in South-East Asia. In this way, it intends to develop a method for assessing the overall resilience of PHC facilities in this part of the world, as well as formulating a set of innovative propositions that bridge preparedness and response, engineering and environmental controls, and build resilience towards the impacts of climate change and improve environmental sustainability of PHC facilities.

Within recent literature regarding environmental performance for healthcare facilities, topics like indoor environmental quality, solid waste management, and life cycle sustainability can be found. However, on the specific topic of environmental or sustainability assessment, some research exists but it is limited. Ali et al. (2022) analyzed existing rating systems like LEED (Leadership in Energy and Environmental Design) and BREEAM (Building Research Establishment Environmental Assessment Method) to assess healthcare buildings for their sustainability so as to improve their environmental performance, whilst Castro et al. (2015) developed 52 sustainability indicators over various dimensions of sustainability to assess and support decisions for the design of new or retrofitted healthcare facilities in urban settings of Portugal.

The literature nevertheless highlights that healthcare buildings are more complex compared to other types of buildings due to their intensive and continuous operation and high energy consumption for electrical, thermal, and ventilation purposes, especially with the use of 24-hour equipment requiring constant energy supply, distinct work zones with various energy requirements, as well as having a high volume of people and movement (Castro et al., 2015; Ali et al., 2022). This implies the need for a more nuanced assessment of healthcare facilities with respect to environmental performance. Notwithstanding, existing literature may not differentiate the needs of healthcare buildings between urban and rural settings, as well as the variation in size and scope of such facilities across different contexts. Although existing Healthcare Building Sustainability Assessment (HBSA) methods, such as LEED, BREEAM, CASBEE (Comprehensive Assessment System for Built Environment Efficiency), and Green Star, cover environmental sustainability particularly in terms of energy efficiency, indoor environmental quality, and waste management, they have limited scope regarding the adaptability and flexibility for climate change and mass casualty incidents, safety across multiple dimensions, and infectious diseases prevention and control particularly in terms of protecting the well-being of patients, medical, and administrative staffs (Castro et al., 2015).

Hence, this series of summer schools exemplifies a line of inquiry that seeks to fill an important gap in research regarding the environmental performance assessment for healthcare centers, particularly in South-East Asia, especially in terms of factors such as climate resilience, environmental sustainability, IPC, and safety. The aforementioned WHO and Pan American Health Organization (PAHO) documents introduce detailed checklists to verify distinct issues but are not operationalized nor presented as comprehensive assessment tools. This research and the development of the CRAS seeks to overcome this issue particularly for South-East Asian peri-urban or rural healthcare centers, whilst also broadening the scope of PHC sustainability and performance to cover environmental and climate change issues, IPC, and safety, into a comprehensive tool.

2.2 Summer School Background

Before clarifying the development and output of the proposed environmental assessment method, the background of the workshop and project initiative is outlined first. The WHO-Téchne network was established as part of the WHO response to the COVID-19 pandemic. It provides technical assistance to member states in all WHO Regions by making health settings and structures safer, reducing the risk of hospital-acquired infections, and improving environmental aspects of health facilities. It also prepares for and responds to public health crises with urgent and customized support, such as research activities and developing guidance, manuals, and tools. Téchne engaged in this series of international summer schools as part of its long-term aim of national and international capacity building through multidisciplinary, community-based, and informed approaches that create safer, healthier, equitable, and more sustainable healthcare systems.

A summer school in 2022 was designed as a pilot project for the collaborative efforts of a consortium of Thammasat University, KU Leuven, and WHO Téchne. In the wake of the COVID-19 pandemic, this trial summer school edition sought to gain specific knowledge and insights on how to use ventilation, temperature, humidity, and daylighting control strategies for infection prevention and control (IPC) within the context of mainland South-East Asia (Lo & De Wandeler, 2024; De Wandeler & Lo, 2025). Following the success of this pilot project, the organizing consortium was broadened to several Thammasat University faculties, KU Leuven, WHO Téchne, and the WHO Country Office for Thailand for the 2023 summer school. In 2024, the Faculty of Architecture of Chiang Mai University took over the role of TDS as organizer and host. The remainder of this paper focuses on the first part of this process, being the methodology and output produced during the 2023 summer school.[1]

3. Methodology: Summer School Process

The methodology employed in our research involved an iterative process moving from PHC case studies, to checklists, to comparison of case studies, then categorization and recategorization of the checklist items, to testing the checklist on the Thai case study and analysis of the results, to fine-tuning the checklist and the visualization of the indicators, which then led to the development of the draft online assessment tool (Figure 1). As mentioned, the 2023 summer school spanned one month, comprising two components of two weeks each. The following outlines the teaching and learning activities leading up to the development of the draft Comprehensive Resilience Assessment System (CRAS) for primary healthcare facilities.

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1 The methodology used in this paper can be distinguished between that of a research methodology and a pedagogical research-by-design methodology. “The core elements of a research by design approach are a continuously interactive setting, in which participants in the design process are placed in the position to creatively exchange, collaborate and develop new knowledge together.[...] Through research by design new pathways are explored, people come up with innovative ideas and concepts that they would not encounter in a regular research or design process. The process is thought-provoking and binding. The results are not final spatial solutions, but merely conceptual innovations that could help to understand and deal with wicked problems.” (Roggema, 2017, pp. 15-16). This research-by-design ‘pedagogical methodology’ or trajectory covers the entire cycle of summer schools over multiple years and therefore (a) goes beyond the scope of this paper and (b) can only be covered in its entirety upon completion of the cycle in 2025.

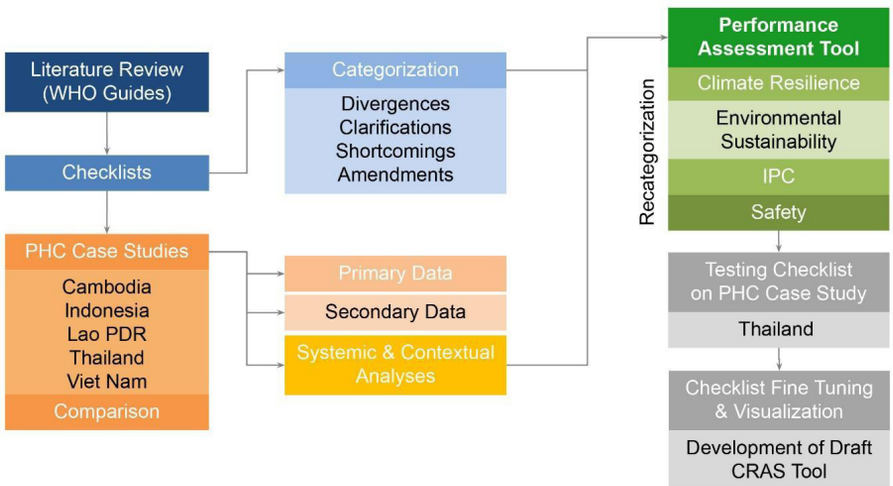


Figure 1. Summer school methodology flowchart by Author

The workflow for the first component of the study (July 1 - 15, 2023) consisted of a hybrid-online preparatory phase in the countries of the participating partner institutions. In the first week, various instructors of the partner institutions shared online lectures via a Learning Management System and publicly uploaded videos (Thammasat Design School Official, 2023). These modules included introductions by a representative of the WHO Country Office for Thailand, the coordinator of WHO-Téchne, and the summer school coordinator. These presentations were followed by lectures on primary healthcare facilities, infection prevention and control (IPC), natural hazard preparedness and disaster risk reduction, resilience to climate change and decarbonized green design of PHC facilities, and concluded with summative overviews on systems thinking and systemic design. This series of online modules also offered hybrid Q&A sessions that helped orient the participants and prepare them for conducting the case studies.

3.1 PHC Case Studies

On-site activities in the respective participating countries were the focus of the second week. The task was to conduct field visits of selected primary healthcare centers in flood-prone suburban or rural areas for case study analysis, observation, and data-gathering. The case study was divided into two parts - 1) systemic contextualization and 2) a preliminary checklist to describe the PHC facility.

In more detail, the first part sought to contextualize the PHC facility following a presentation template, mapping it across various scales, namely Extra Large (city or district scale), Large (district or sub-district/ municipality scale), and Medium (neighborhood scale of 400m x 400m). Generally, the maps had to analyze and locate the city center (historical, cultural, CBD, etc.), major infrastructure (highways, ring road, airport, etc.), healthcare facilities (hospitals, clinics or other PHC centers, general practitioners, pharmacies, or even medical education facilities), schools and educational institutes, mass evacuation facilities, as well as any geographical elements (mountains/valleys, fault lines, etc.) or hydrological elements (sea, rivers, canals, ponds, floodplains, etc.) that could present natural hazards to the PHC center. Each participating team also researched the socio-economic context of the PHC center and the population it serves by holding focus group discussions with the staff, nurses, and various patients/users.

The last component of the systemic analysis of the PHC center was to focus on the Small scale, i.e. the analysis of the PHC facility itself, which included identifying the opening hours, permanent/part-time staffing, services offered, rooms and room sizes (detailed in a schedule of spaces), medical equipment, as well as the years of operation (based on year of construction/opening) as well as any remodeling or modification to its structure. This overview was accompanied by floor plans of the case study PHC facility, indicating zones for staff, patients, and common areas (Figure 2).



Figure 2. Floor plans of the Thai case study PHC, Koh Kerd Sub-District Health Promoting Hospital, Bang-Pa In District, Ayutthaya Province, Thailand, by Author

3.2 Checklists

The second, and more significant, part of the case study was to undertake an assessment of the PHC facility using a 'preliminary checklist' as prepared by the KU Leuven team based on four key WHO guidances and documents (World Health Organization [WHO]; WHO, 2021; WHO & PAHO, 2015; (World Health Organization [WHO], 2018). The 120 items in this checklist were clustered into five initial categories: Large/Medium scale - hazards, Small scale - hazards, Small scale - safety, Small scale - utilities (water and energy), and Small scale - provisions. An initial three point (low, medium, high) scoring system was used as part of this checklist assessment, which will be further explained in the following Results section. To wrap up their assessment, all teams then summarized how their PHC facility performed regarding each of the aforementioned categories into a standard presentation template.

3.3 Comparison of Case Studies

The third week brought all the participants and instructors together at TDS, in Thailand, for two-weeks of on-site activities. This began on 18th July 2023 with on-site orientation and an official opening ceremony, after which the WHO-Téchne coordinator and the summer school coordinators presented the rationale, program, and objectives of the workshop. Following an opening lecture by TU Faculty of Public Health on the topic of Disaster Management in Thailand, each of the partner university teams presented their respective case studies of primary healthcare facilities. This allowed all participants to see the similarities and differences of the PHC facilities as they reviewed the systemic analysis and contextualization as well as the PHC facility

performance on the various indicators of the preliminary checklist. The KU Leuven team wrapped up the successive presentations with a comparison of the aggregated results of all the PHC facility case studies providing a preliminary understanding of the performance of each facility according to the original criteria of the preliminary checklist.[2]

3.4 Categorization

To better align with the overall workshop themes of climate resilience and environmental sustainability, the participants who had thus far been associated with their home university, regrouped into multicultural and multidisciplinary teams to re-examine the preliminary checklist and then presented proposed amendments as a revised version of the checklist assessment. Whereas the case study assessment comprised, on the one hand, spatial assets according to the scale levels of Large, Medium and Small, and on the other hand, the criteria of the preliminary checklist, a new categorization was put forward based on five new categories: climate resilience, environmental sustainability, infection prevention and control (IPC), safety, and context. Teams discussed which checklist items could be removed, added, or rewritten based on relevance, association, or categorization of items. They had to justify their logic and decisions as to why certain items should be in certain categories. The intermediary presentation of this process helped the instructors and coordinators to recognize that the category of 'context', derived from the case studies' spatial analysis, stood out as a location-bound asset as opposed to the other four categories that were associated with specific themes or functions. To lift this incongruity, the spatial aspects reported under 'context' were integrated and described in terms of the PHC facility as a physical structure, and its functional aspects were viewed as part of the four remaining categories.

The result of this segment of the workflow was a final recategorization of the checklist items into four 'domains' and three 'dimensions'. The four domains represented the four main categories of the assessment criteria to evaluate the environmental performance of the PHC facility: climate resilience, environmental sustainability, infection prevention and control (IPC), and safety. Across these four domains, the criteria to assess PHC performance cover three dimensions, namely, facility, energy, and WASH (water, sanitation, and hygiene) (Table 1).

The definitions of the four domains are as follows:

1. **Climate Resilience:** 'Climate resilient health systems are capable of anticipating, responding to, coping with, recovering from and adapting to climate-related shocks and stress, so as to bring about sustained improvements in population health, despite an unstable climate' (WHO, 2020, p. 22).

2. **Environmental Sustainability:** 'Environmentally sustainable health systems improve, maintain or restore health, while minimizing negative impacts on the environment and leveraging opportunities to restore and improve it, for the benefit of the health and well-being of current and future generations' (WHO, 2020, p. 22).

2 The KU Leuven team did not conduct a case study in Belgium, as this was outside of the scope of the South-East Asian region and instead prepared the preliminary checklist via Google Forms and then data-mined the results of the partner universities' case studies for analysis and presentation.

3. **IPC (Infection Prevention and Control)**: Infection prevention and control (IPC) programs should be required at the national and facility level to prevent health care-associated infection (HAI) and to combat antimicrobial resistance (AMR) (World Health Organization [WHO], 2016).

4. **Safety**: Safety includes structural safety, non-structural safety, safety to hazards, etc. It is important to assess how a healthcare facility will remain operational during emergencies and disasters by understanding the facility's strengths and weaknesses as well as points of action required to improve the safety and disaster risk management capacities (WHO & PAHO, 2015).

Table 1. Four Domains and Three Dimensions of the Assessment Tool (letters indicate the coded prefixes of the checklist items)

		Four Domains			
		Climate Resilience	Environmental Sustainability	Infection Prevention & Control	Safety
Three Dimensions	Facility	CF	EF	IF	SF
	Energy	CE	EE	IE	SE
	WASH	CW	EW	IW	SW

These four 'domains' (main assessment categories) were chosen as they aligned with the summer school objective to assess and improve the performance of PHC facilities in terms of climate resilience and environmental sustainability. They also were based on existing WHO guidances, particularly the *WHO Guidance for Climate-Resilient and Environmentally Sustainable Health Care Facilities* (WHO, 2020) and *Checklists to Assess vulnerabilities in Health Care Facilities in the Context of Climate Change* (WHO, 2021). Furthermore, the three dimensions of facility, energy, and WASH have been adapted from the aforementioned WHO guidances, which specify four fundamental requirements for providing safe and quality care, namely 1) health workforce, 2) water, sanitation, hygiene and health care waste management (aka WASH and waste), 3) energy, and 4) infrastructure, technologies, and products. As the objective of the environmental assessment focuses on the built environment, the health workforce aspect is beyond the scope of the study, thus leaving facility (the built environment aspects of infrastructure, technologies, and products), energy, and WASH (including waste) as the three sub-categories or 'dimensions'.

With this streamlined recategorization in place, the participants regrouped into four teams to work on the domain of their interest and then set out to develop a mid-study presentation of the summer school. Here, each group had to present the definition and key principles of their domain (category) as well as each of their revised checklist items within the three dimensions (sub-categories) (Table 1). The result of these presentations was a 'revised checklist' with approximately 97 items across the four domains (a reduction, filtering, and modification of the preliminary 120 items).

3.5 Testing the Checklist on the Thai Case Study

The fourth and final week of the summer school started with a field visit to the Thailand PHC facility case study to re-assess and test the 'revised checklist'. This PHC was the Koh Kerd sub-district health promoting hospital in the Bang-Pa In district of Ayutthaya province, situated north of Bangkok.

3.6 Checklist Fine-Tuning and Visualization

Following the field visit, the participants were regrouped temporarily by their disciplinary skill-sets to accomplish three tasks, 1) analyze the data from the re-assessment of the PHC facility case study; 2) define a matrix of spatial requirements for PHC facilities based on previous international comparative data; and 3) diagrammatically visualize the individual checklist items into graphical illustrations for each CRAS criterion to enhance user-friendliness for targeted users regardless of technical knowledge. The objective of this split task was to allow for further fine-tuning of parts of the checklist and the compilation of a finalized assessment tool (updated checklist).

Under the guidance of the summer school coordinators and instructors, the student teams then worked towards a pin-up of the draft final presentation slides for review. Here the participants got to see how all the parts fit together into a cohesive whole (see Figure 3). The instructors and peers provided the necessary feedback to reinforce key issues and refine the slides towards the final presentation. This highly productive and collaborative session confirmed the structure, order, format, graphics, and delivery of the presentation.



Figure 3. Group work and semi-final pin-up of the presentation slides for interim review and feedback, by Author

3.7 Draft of Online Assessment Tool

The participants delivered a final presentation at the end of the four week workshop to a panel composed of instructors, the dean of Thammasat Design School and a representative of the WHO Country Office for Thailand. They presented the logic and components leading up to the Comprehensive Resilience Assessment System (CRAS) for primary healthcare facilities, which included: 1) objectives, target audience, and spatial requirements matrix, 2) the checklist items under the four domains of climate resilience, environmental sustainability, IPC, and safety, 3) the analysis of the results for the Thailand PHC facility case study, and 4) the online assessment tool (finalized checklist items as presented via Google Forms, with 100 items, which included refinements and additions to the 97 items identified at the interim stage) (see Figures 4-7) (Thammasat Design School & KU Leuven, 2023).

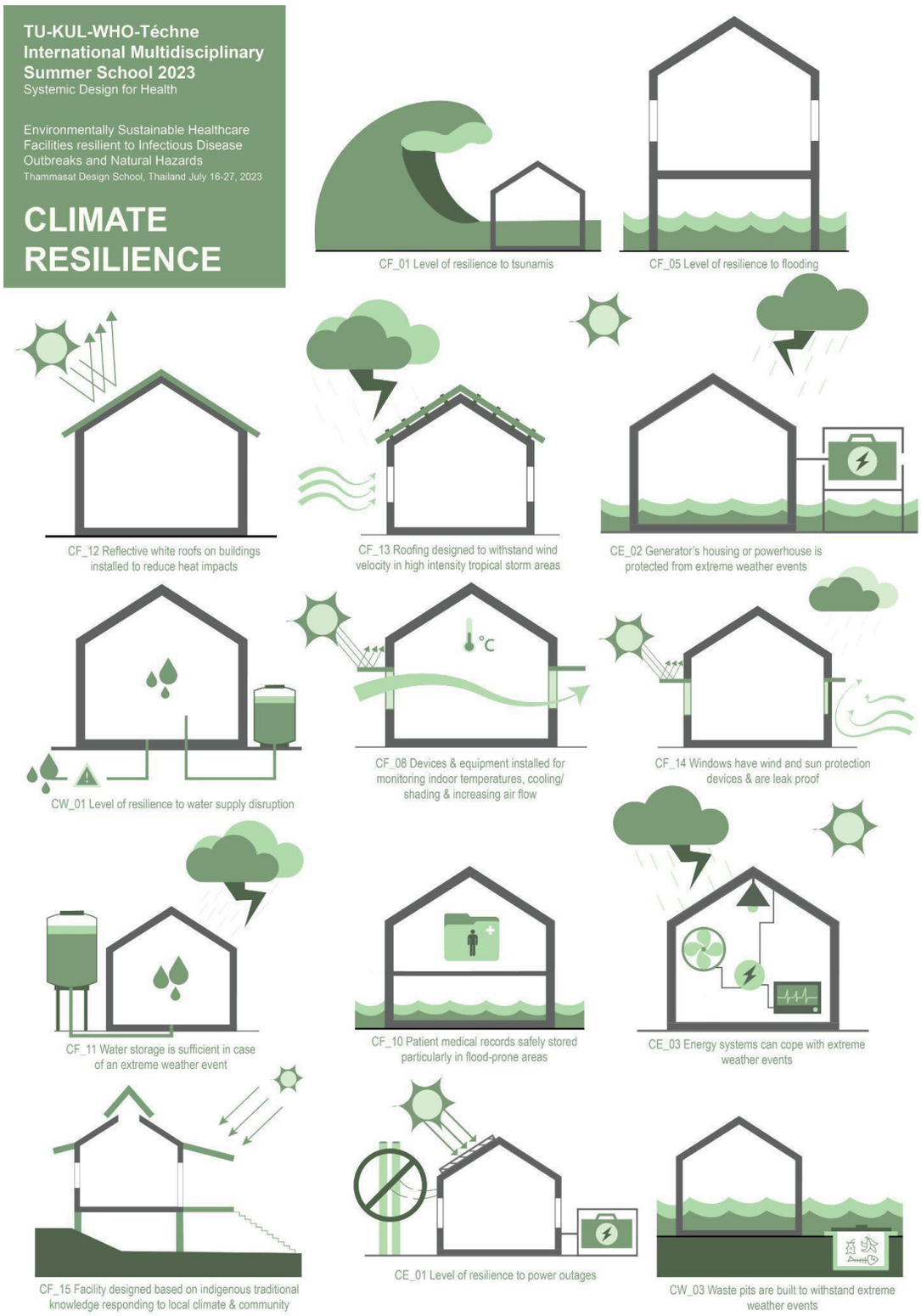


Figure 4. Assorted items of the Climate Resilience domain of the CRAS by Author

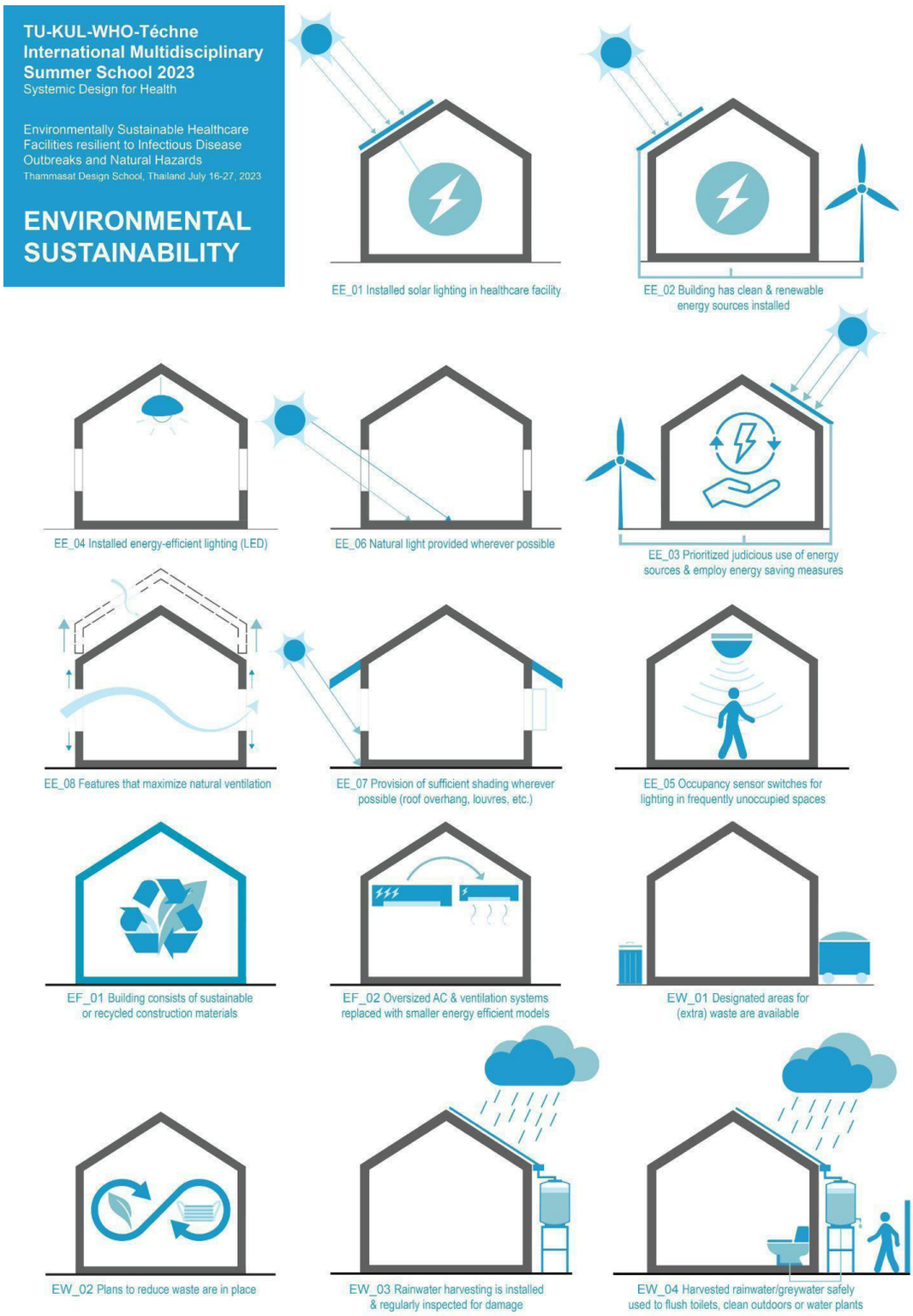


Figure 5. Assorted items of the Environmental Sustainability domain of the CRAS by Author

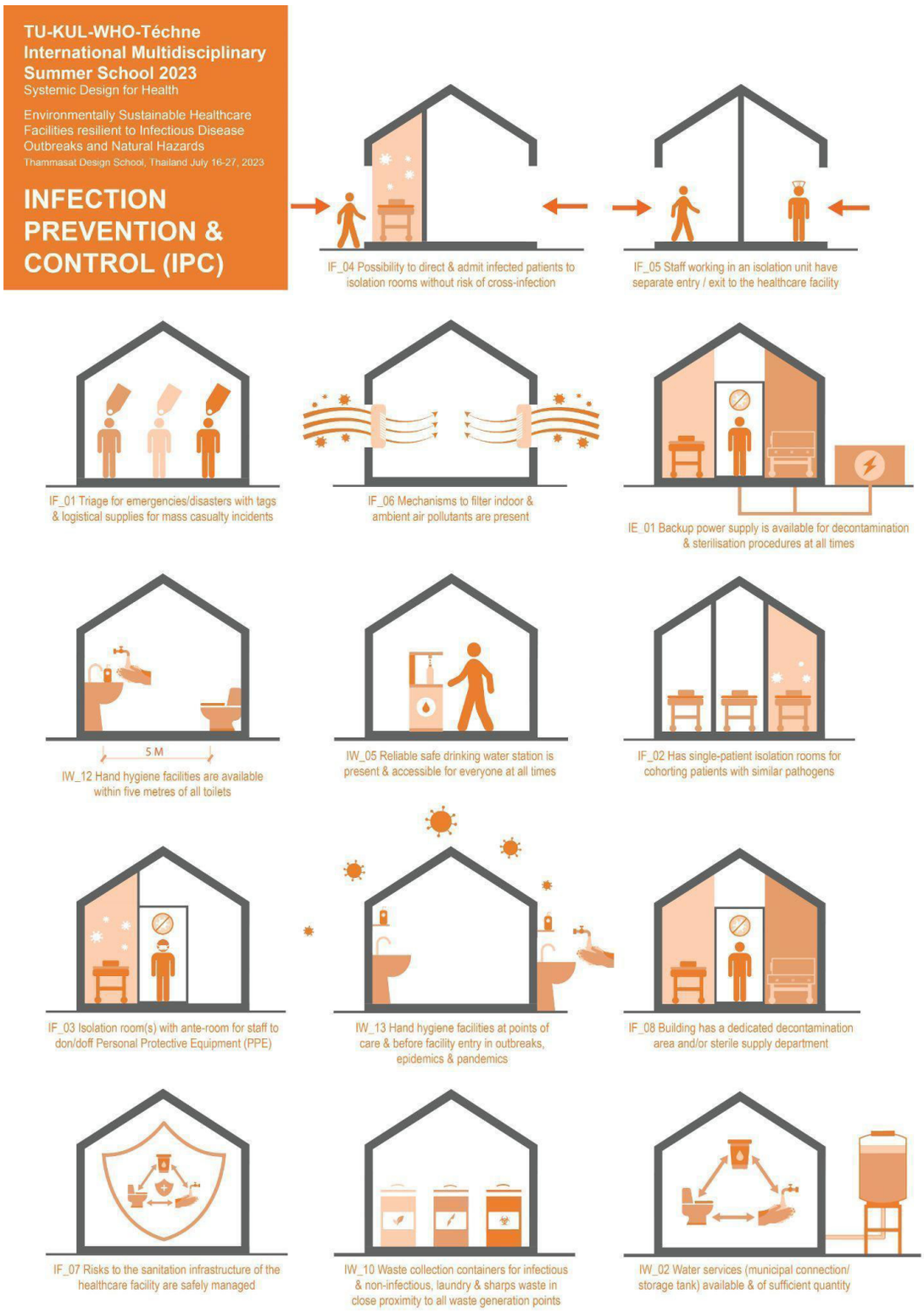


Figure 6. Assorted items of the Infection Prevention and Control (IPC) domain of the CRAS by Author

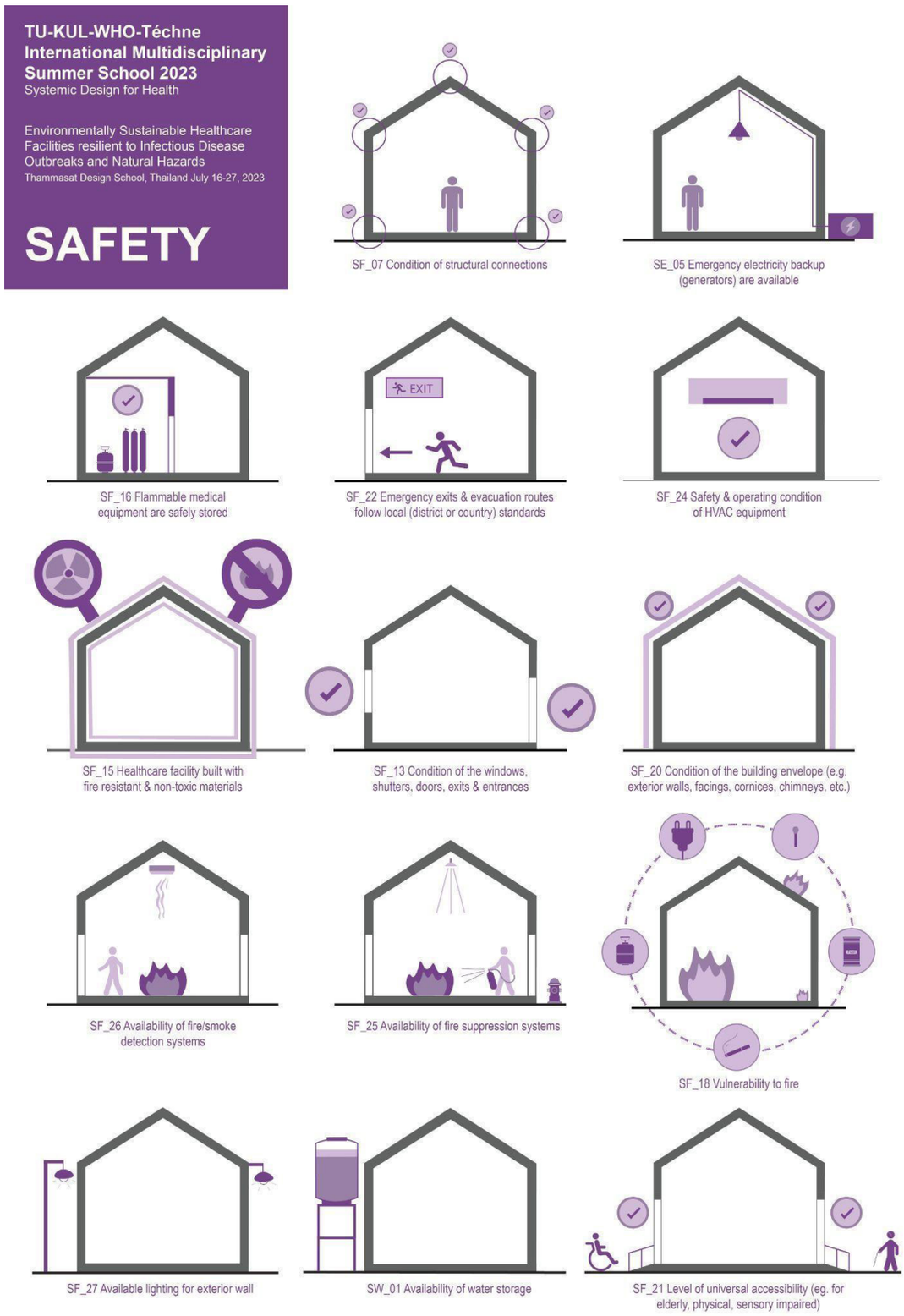


Figure 7. Assorted items of the Safety domain of the CRAS by Author

Before explaining the CRAS output, it is worth mentioning the relevance and reliability of the checklist items. The relevance of the items derives from: 1) the sources (WHO/PAHO), 2) the criterion that only items relevant for PHCs were adapted from these sources, and 3) the preliminary evaluation of these items by experts at the WHO health emergencies program. Table 2 indicates how the CRAS is a synthesis of existing relevant metrics/tools, but also how the CRAS differs from these. The reliability of the checklist items was pilot-tested by: 1) the first round of PHC case studies by country, 2) through the comparison of these case studies, and 3) through the cross-examination with the site visit of the Thai case study. Moreover, further testing took place in preparation of summer school 2024 and its future iterations.

Table 2. Comparison between Existing WHO and PAHO Tools/Guidances with CRAS

Checklist / Tool	Domains / Categories	Dimensions / Checklist
(CRES) *WHO Guidance for Climate-Resilient and Environmentally Sustainable Health Care Facilities* (WHO, 2020)	1. Climate Resilience 2. Environmental Sustainability	1. Health workforce 2. Water, sanitation, hygiene & health care waste management 3. Energy 4. Infrastructure, technologies, and products
(CCC) *Checklists to Assess vulnerabilities in Health Care Facilities in the Context of Climate Change* (WHO, 2021)	1. Climate Resilience 2. Environmental Sustainability	1. Health workforce 2. WASH & health care waste 3. Energy services 4. Infrastructure, technologies, products, processes
(HSI) *Hospital Safety Index: Guide for Evaluators* (WHO & PAHO, 2015)	1. Hazards affecting safety 2. Structural safety 3. Nonstructural safety 4. Emergency & disaster management	Various items relating to the four safety domains
(IPC) *Infection Prevention and Control Assessment Framework at the Facility Level* (WHO, 2018)	1. IPC program 2. IPC guidelines 3. IPC education & training 4. HAI surveillance 5. Multimodal implementation strategies 6. Monitoring/audits of IPC practices & feedback 7. Workload, staffing & bed occupancy 8. Built environment, materials & equipment for IPC at facility level	Various items relating to the eight IPC domains
(CRAS) Comprehensive Resilience Assessment System (proposed)	1. Climate Resilience 2. Environmental Sustainability 3. Infection, Prevention & Control 4. Safety	1. Facility 2. Energy 3. WASH & Waste

4. Results: Development of Comprehensive Resilience Assessment System (CRAS)

As discussed in the previous section, the academic output of the summer school was a draft Comprehensive Resilience Assessment System (CRAS) for primary healthcare facilities in South-East Asia, seeking to ensure that such facilities are dignified settings where people can seek care, and biomedical and psychosocial services be delivered effectively. The iterative multidisciplinary collaboration to achieve this result revolved around a

'research-by-design/design-by-research mode of enquiry' (Doucet & Janssens, 2011, p.2) through which the participants transformed selected checklist items from various WHO guidances (WHO, 2020; WHO, 2021; WHO & PAHO, 2015; WHO, 2018) and other UN documents, including: *A Practical Guide to Climate-resilient Buildings and Communities* (Gupta et al., 2021) and the *World Cities Report 2022: Envisaging the Future of Cities* (UN-Habitat, 2022) into a comprehensive draft CRAS tool for assessing primary healthcare facilities' performance.

The assessment variables were categorized according to four domains: climate resilience (C), environmental sustainability (E), infection prevention and control (I), and safety (S). Within these four domains three dimensions were distinguished, namely, facility (F), energy (E), and WASH (W - water, sanitation, and hygiene) (Table 1). By way of example, 'CF_05 Level of resilience to flooding': C refers to the Climate Resilience domain, while the F refers to the Facility dimension, so this item is about how climate related hazards affect the PHC center at the facility level, in this case the building's resilience to floods. While 'CE_01 Level of resilience to power outages' also is in the Climate Resilience domain, in this case, the E represents the Energy dimension, so this item is about the building's performance within the scope of energy, particularly in the case of power outages due to climate related hazards. To give an example from another domain, 'EE_02 The health care facility has clean and renewable energy sources installed' is from the Environmental Sustainability domain, under the Energy dimension. This item addresses the environmental performance of the building in terms of its production and consumption of energy, particularly whether it uses clean and renewable energy sources such as solar or wind.

For each item of the assessment tool, the level of resilience or capacity was rated according to three possible answers: 1) Low, unable, 2) Medium, in progress, incomplete, and 3) High, completed, achieved. These three responses also implied a scoring system, where one point was given for low, two points for medium, and three points for high (Table 3). Given that each domain has a total set of checklist items within their dimensions, each domain will thus have a total score, with the highest score being the number of items in each domain multiplied by three points (Table 4). The PHC facility can hence be quantitatively assessed according to each domain, with its score indicating its performance (see Figure 8).

Table 3. Scoring System for Checklist Items

Level of Resilience / Capacity	Score
Unavailable	0 points
Low, unable	1 point
Medium, in progress, incomplete	2 points
High, completed, achieved	3 points

Table 4. Total Number of Items in Each Dimension for Each Domain, and Total Possible Score

	Facility	Energy	WASH	Total Items	Total Score (Items x 3)
Climate Resilience	15	3	5	23	69 points
Environmental Sustainability	3	8	4	15	45 points
Infection Prevention & Control	8	1	15	24	72 points
Safety	30	6	2	38	114 points



Figure 8. Graphs showing the scores and performance for each domain - Climate Resilience, Environmental Sustainability, Infection Prevention and Control, and Safety- as assessed by the students for the Thai case study (Koh Kerd sub-district health promoting hospital, Bang-Pa In district, Ayutthaya, Thailand). As each domain has a different number of checklist items within each dimension, therefore it would be incomparable to evaluate the domains according to their 'raw' or absolute scores, hence these scores were weighted (levelling each domain to a total of 100%) so as to be measured as a percentage to make each domain comparable to each other, by Author

Having thus defined both the qualitative and quantitative aspects of the distinctive variables, the summer school also sought to operationalize the 'assessment tool' in its totality by drafting the objectives for its use and identifying which users and what target audience would benefit from it.

The draft CRAS tool aims to promote and implement environmentally sustainable practices in the provision of PHC services. Its integrated assessment of climate resilience and environmental sustainability includes measuring the efficient management of energy uses, water supply and treatment, sustainable procurement, and hazardous waste disposal. By following up on these indicators, PHC facilities could improve their operations minimizing negative impacts on the environment while maintaining high-quality healthcare services. Besides its use to assess and enhance PHC facilities' resilience to climate change and environmental sustainability, the tool also assesses and monitors a facility's safety (structural and non-structural) as well as its spatial capacity to safely manage infectious diseases, continued delivery of essential services, and surge planning, and thus helps ensure a safe environment for patients and staff. The items' quantitative assessment is indicative of domain performance, for instance, in the Thai case study, the Environmental Sustainability performance was relatively low compared to the other domains. This primarily was due to a lack of clean and renewable energy sources such as solar or wind. At the same time, the Safety domain performed quite well as it did not show any structural deficiencies despite being around 50 years old at the time of assessment and having withstood multiple floods over the years (Figure 8).

The tool also can be used to collect data to provide specific guidance for both immediate and future action to resolve identified gaps. As per the above example of the Thai case study, a potential and partial remedy for the low Environmental Sustainability score would be to install solar panels on the roof. Thus, such a tool becomes particularly helpful for the PHC facility to be better prepared and ready to respond to natural hazards or infectious disease outbreaks, which also may require additional modifications or repurposing of the structure and/or spaces.

Moreover, this tool can enhance healthcare preparedness by providing PHC healthcare professionals with guidance on climate-related health risks. Staff can be equipped with the relevant knowledge and tools required to monitor, anticipate, manage, and adapt to health risks associated with climate change. With these improved preparedness and response measures, the PHC facility can more effectively protect the health and well-being of patients, staff, and the wider community in the face of climate-related challenges.

Therefore, the users benefitting from the tool and its target audience include: primary healthcare facility managers, technical officers, logisticians, WASH specialists, and healthcare facility engineers and architects. Users can either print out the checklists and fill them out by hand or fill out the online version of the tool on their smartphone, tablet, or laptop while visiting a facility and interviewing staff, patients, or service providers (link to draft CRAS).

5. Conclusion and Way Forward

In summary, this paper details the development of the CRAS, an online draft graphical assessment tool to assess the performance of primary healthcare centers in suburban and rural areas in South-East Asia. This outcome aimed to establish the basis for the development of guidelines for the design of climate-resilient and environmentally sustainable primary healthcare facilities, which can respond to infectious disease outbreaks and natural hazards. The findings show how the CRAS, as an integrated tool, can assess PHCs and identify gaps in its performance, from the efficient management of energy, water supply and treatment, structural and non-structural safety, to hazardous waste disposal. The proposed CRAS has implications beyond this summer school, as upon endorsement by WHO, this tool will be made available to WHO-Téchne members, the WHO Country Office for Thailand and other WHO units, as well as to all participating partner universities and stakeholders, in its efforts to support national and local governments to improve the environmental performance and impact of PHCs.

By the time of submission of this manuscript, the next steps had already been initiated, with the 2024 summer school which gathered participants from most of the same partner universities as in 2023, albeit in a different setting at the Faculty of Architecture of Chiang Mai University (ARCH-CMU). It has expanded its transdisciplinary approach by seeking a broader consultation with stakeholders and beneficiaries and subjecting the CRAS to the scrutiny of scholars and expert opinions (Hadorn et al., 2008; Jahn et al., 2012; Rigolot, 2020). As a new contributor to the organizing consortium, ARCH-CMU will further efforts to strengthen collaboration with the Thai Ministry of Public Health (MoPH) through the WHO Country Office for Thailand:

- Complementing the matrix on primary healthcare facilities' comparative spatial usage with the standards currently advocated in Thailand;
- Selecting a case study in a flood-prone suburban area of Chiang Mai, in consultation with the WHO Country Office for Thailand and the MoPH; and
- Exploring how the ongoing project can be fine-tuned and the resulting CRAS and design brief can contribute to MoPH in developing a national guideline.

In a process analogous to the one described in this paper, the partner universities in the 2024 summer school tested the CRAS in case studies in their respective countries, compared the test results and fine-tuned the CRAS, expanding its indicative value to a detailed design brief. After finalization, the CRAS and the design brief will be submitted to WHO authorities for approval and application for primary healthcare facilities in South-East Asia and the Western Pacific Regions. This process will wrap up a three-year cycle of joint, iterative endeavors to fine-tune a research-by-design/design-by-research mode of enquiry. Doucet and Janssens characterized this approach in design thinking as a kind of knowledge production that turns around 'the integration of discipline and profession (theory and practice), an ethical dimension and an important element of experimental, designerly modes of inquiry' (Doucet & Janssens, 2011, p. 2). At the conclusion of the 2023 project, the instructors of the consortium and the partner universities acknowledged this perception in their final comments by emphasizing the implications of this summer school, such as how the initiative offered practical knowledge (case study fieldwork) through collaborative exchange, capacity and resilience building, coupled with valuable learning materials (online learning resources and lectures) relevant not only to the design field, but also to building science, environment, and society. In conclusion, the progression of this summer school cycle highlights the need for a multidisciplinary whole-of-society approach to transform complex global challenges of today into inclusive, healthier, and sustainable solutions for tomorrow.

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Human Subjects

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Data Availability Statement

Due to data confidentiality issues, the data presented in the manuscript are not freely accessible.

Use of Generative Artificial Intelligence (AI) and AI-Assisted Technologies

No Generative Artificial Intelligence (AI) and AI-Assisted Technologies were used at any stage of this paper.

Author Contributions

Conceptualization, A.Y.W.L. and K.D.W.; methodology, A.Y.W.L. and K.D.W.; investigation, A.Y.W.L. and K.D.W.; resources, A.Y.W.L. and K.D.W.; writing – original draft, A.Y.W.L. and K.D.W.; writing –review and editing, A.Y.W.L. and K.D.W., visualization, A.Y.W.L.; supervision, A.Y.W.L. and K.D.W.; project administration, A.Y.W.L . and K.D.W.; funding acquisition, A.Y.W.L. and K.D.W. All authors have read and agreed to the published version of the manuscript and declared no conflict of interest.

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