COVID-19 SCREENING STATION DESIGN FOR SEMI-OUTDOOR ENVIRONMENTS NEAR HEALTHCARE FACILITIES

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Abstract

Worldwide, healthcare institutions face acute challenges in responding to the ongoing COVID-19 pandemic, including the difficulty of protecting patients and staff unrelated to the virus from potentially infected people seeking the COVID-19 test. An isolated facility solution allows hospitals to separate existing facilities and not disrupt general hospital operations and protect the affected operating medical staff and potentially infected patients from virus spread. This research aims to develop a COVID-19 screening station prototype by rationalizing existing solutions for virus testing facilities, adapting them into flexible modular units capable of suiting Thai hospitals regarding local conditions and budget limitations. Consultations with medical doctors and experts supported the design development, taking reference to stipulated patient treatment processes. A working, functional prototype screening station was installed for use and testing at a hospital. Research outcomes suggest that the proposed design solution for a modular screening station and the constructed prototype for semi-outdoor solutions are considered safe, operational, and suitable for implementation near healthcare facilities. As a feasible, low construction cost solution, offering a low risk of contamination, the modular and flexible structure of the COVID-19 screening station enables adaption to individual needs and functional requirements or cope with existing site conditions. A project-implementation review (PIR) documents project usage, operation, and function recording and improvement suggestions for development, with future work foreseeing its design implementation. The prototype solution's further developed results are to be implemented in various hospitals in Thailand within a short period. Funding for this research came from the Faculty of Architecture and Design (SoA+D) of King Mongkut Technical University Thonburi (KMUTT), supporting research in architecture and its application in Thai society.

Keywords: COVID-19 Screening Station, Design for Safety, Pandemic Resilience.

1. Introduction

In Thailand, as one of the first countries outside of China to report a Covid-19 infection (Schnirring, 2020), the virus pandemic has developed somewhat moderately, with relatively low infection numbers per day. The Department of Disease Control (DDC) publishes daily status reports detailing confirmed cases, deaths, and the number of people tested (DDC, 2020). The statistics relate to Persons Under Investigation (PUI) tests, in which only people with plausible symptoms and contact with likely infected qualify for testing. Providing safety is among the many challenges that hospitals face concerning the COVID-19 epidemic. Medical staff must rely on personal protective equipment (PPE), ensuring they are not infected while treating potentially affected patients. With the pandemic spreading, PPE need has risen sharply with the resulting shortcomings in the supply, increasing costs, and a rise in generating hazardous waste (Nowakowski, Kusnierz, Sosna, Mauer, & Maj, 2020).

In standard hospital designs, the air supply is typically provided by air conditioning systems that do not offer the necessary filtering and pressurization of air. Such technology is only installed in operating theatres and isolation stations to reduce possible infections and contaminations (AIA, 1996). Ensuring proper indoor air treatment is critical in the ongoing crisis but cannot be provided easily due to time or cost constraints. With the growing need to conduct sampling, an isolated facility solution allows hospitals to disconnect from general hospital operations to protect staff and inpatients. In addition to avoiding direct contact with PUI, such separation also minimizes the risk of contamination of the hospital's interior and the increased need for disinfection. This research aims to provide an off-site screening station at a moderate distance to health care facilities that will protect HCW from coronavirus infection while taking samples. A modular prototype design is to match hospitals in Thailand regarding local conditions and budget restrictions through design rationalization and adaptation of existing solutions. The expected result is a viable design solution for current and future PUI treatment processes during COVID-19 testing by integrating standard operating procedures (SOP) to collect specimens at the least risk and comply with specimen storage standards. It includes the need for air handling to mitigate the possible spread of airborne infection and germs proliferations on surfaces. The prototype design considerations adapt and develop existing design solutions to a flexible, mobile, sturdy, reusable, yet cost-effective solution. As a result, the test units could be installed nearby health care facilities such as covered or uncovered outdoor areas, parking lots with sufficient height clearance, or tent structures to avoid potentially infected people needing access to the hospital.

2. Literature Review

2.1 Coronavirus (COVID-19) Testing

Detecting COVID-19 infections in humans requires testing (Hoffmann, et al., 2020). Two main types of COVID-19 tests can currently identify the SARS-CoV-2 virus; they include methods for detecting the virus's existence and finding antibodies produced in response to an infection. For newly infected, the reverse transcription-polymerase chain reaction (RT-PCR) testing method is the most reliable way of detecting the presence of viruses in humans. In Thailand, the RT-PCR sampling via nasopharyngeal swab is the primary testing method foreseen for individuals showing apparent infection symptoms. According to Thai government guidelines, COVID-19 standard tests are only allowed for PUI, with testing conducted at selected government hospitals (DDC, 2020). The DDC is notified if a test result is positive. Yet, non-government hospitals started offering a testing service that has been developed specifically for Non-PUI. Several approaches for conducting screening and sample taking are utilized, categorizing as on-premises, off-premises, and drive-thru tests.

A drawback of on-premises testing is that potentially infected patients are still treated within the hospital's indoor spaces, potentially contaminating indoor air, surfaces and interfering with building operations. Off-premises testing derives from China and South Korea (Lee, 2020), where outdoor testing facilities, such as tents have been used. With a physical separation from potentially infected, PPE-wearing medical staff conduct examination and testing through a transparent vinyl, acrylic, or glass panel via integrated gloves. Information on the design and planning of separate facilities to screen and test potentially infected coronavirus patients assert the need for strict physical distancing between medical personnel and potentially infected people and the need for air control, including the utilization of natural ventilation in semi-outdoor areas (WHO, 2020). Fearing possible contamination that affects overall building operations, some facilities have resorted to conducting sampling by taking tests outdoors via implementing a drive-thru scenario. Vejthani or Vibhavadi hospital (Parpat, 2020), where HCW, fitted with PPE, then conduct examination and sample taking directly at the opened car window. The approach has been reported to have that HCW performing in PPE gear feel exhausted in a short time because the protective equipment is not designed for use outdoors in tropical climates (The Thaiger News, 2020).

2.2 Safety Measures

Social or physical distancing (Harris, et al., 2020) is a non-medical measure to prevent infection by maintaining a physical distance between people and reducing the frequency with which people come into close contact (Johnson, Sun, & Freedman, 2020). Physical distancing measures are beneficial when infectious diseases develop through droplet contact (coughing or sneezing), direct and indirect physical contact, or airborne transmission (Ryan, 2009). Concerning COVID-19, more than two meters from one another, and the avoidance of larger group assemblies is advisable (Pearce, 2020). This measure helps to ensure that infection peaks in the epidemic flatten out. Other suggestive measures associated with infection prevention are regular personal hygiene such as simple handwashing or human behaviour regulations, such as avoiding contact via handshake, hugging, etc. Fomite transmission is viewed as another possible way of spreading SARS-CoV-2. To minimize fomite transmission, exposed surfaces with reduced detailing of joints or corners allow for simple and effectively regular cleaning. Specific materials also reduce transmission via surfaces such as antimicrobial coatings with self-cleaning functionality (Brownell, 2020).

National requirements of indoor environments for airborne infectious diseases in Thailand suggest air quality control of spaces where infected patients and medical workers are simultaneously present (Bamrasnaradura Infectious Disease Institute, 2017). Accordingly, air treatment should follow guidelines for avoiding airborne infections as practiced in facilities for highly infectious diseases. Such as utilizing depressurized air to remove possibly contaminated air volumes surrounding patients, pressurized air to protect areas where medical workers operate (AIA, 1996). Using high-efficiency particulate absorbing (HEPA) filter systems for effective filtration of SARS-CoV-2 should be viewed as an additional measure for infection control (Qian, 20118). International organizations, like the WHO, also provide information on the design and planning of separate treatment facilities to screen and treat potentially infected coronavirus patients. The documentation illustrates the need for strict physical distancing between medical personnel and potentially infected people and the need for air control, including the utilization of natural ventilation in semi-outdoor areas (WHO, 2020).

2.3 Design rationalization, prototype testing, and Post-Implementation Review

In general, building design refers to the broad architectural and engineering uses for the construction of buildings. Here, a design methodology can be used in different ways to structure the content and process of problems. Experts and specialists are consulted and participate in an integrated design process to define the tasks and requirements that must be fulfilled. A rationalization of the design can then help consider constraints through partial analysis and synthesis to avoid unnecessary deviations through simplification, reduced complexity, and technological possibilities. With suitable analysis methods such as simulations, prototyping, or the redefinition of requirements, significantly better design solutions can be achieved. A prototype, as an example of a pre-implementation object, allows testing a concept or process. A working, functional prototype represents all or nearly all the functionality that captures an anticipated design's usability and appearance (Lim, 2008).

Survey-based research is used in various medical to gather information about health workers' exercise patterns and professional attitudes towards various clinical problems and diseases (Kelley, Clark, Brown, & Sitizia, 2003). Yet, they are also used for architectural studies, i.e., for space-programming purposes or to expand scientific knowledge in social-related research areas. A post-implementation review (PIR) is typically done after completing a project to assess whether project objectives were met. Steps are understood as surveys with key stakeholders, project goals assessments, post adjustments identification, or the update of lessons learned and ongoing benefits (Dogaru & Dogaru, 2015).

3. Methodology

This research methodology consisted of expert surveys, design rationalization, prototype development and testing, and installation verification. The expert survey was based on typical methods such as individual interviews or a questionnaire. Secondly, design rationalization then used the gathered information to program the screening station design and prototype development. The developed prototype was classified as a full-sized functional screening station, tested in the workshop, and eventually upgraded for use in a Thai hospital before installation. The PIR was then carried out after the screening station's commissioning.

3.1 Survey

Interviews were conducted to gain insight into specific details such as procedures for conducting sampling or existing guidelines and requirements for the staff's safety. Interviewees were medical doctors, hospital managers, construction specialists, a civil engineer (HVAC), and a building contractor with hospital planning and construction projects. Besides, air treatment information ensures safety from virus contamination and design considerations that provide mobility, flexibility, transportation, and cost-effective concerns. A questionnaire was created to find information on the available exterior and semi-exterior areas near hospital facilities interested in having a screening station in their facility. The data assessment included information on the location and size of the respective healthcare facility and its employees, the expectation of the required services, and the availability of external and semi-external areas in the hospital's vicinity that provide the installation and operating infrastructure.

3.2 Design Rationalization

The design rationalization process combined effect findings from the survey collected from case studies to synthesize a design proposal. Essential elements of the rationalization process are documented as follows:

Open and Semi-Outdoor Environments: The utilization of outdoor or semi-outdoor environments for screening stations supports implementing the COVID-19 testing procedure.

Spatial Separation: A physical separation between PUI and HCW is to reduce infection rates. By prioritizing the protection of HCWs from possible virus contamination, they work in physically isolated cabins with controlled ventilation. The use of such a protected interior reduces the need to wear personal protective equipment (PPE), improving working conditions in terms of stress relief and fatigue. PUIs remain in outdoor areas where natural ventilation can quickly distribute outside air around people. By reducing the number of exposed surfaces outside the cabins, the need for disinfection after each procedure is further reduced.

Air-Handling: To prevent virus contamination inside the cabins, these must be equipped with a HEPA filtered air supply and positive air pressure to prevent the ingress of contaminated air. In terms of PUIs left outdoors, this can be beneficial in preventing potential virus spread. Constant air currents disperse droplets in the air faster, thus reducing the possibility of transmission to humans (NHK News, 2020).

Building Code Requirements: Given the size and the low weight of the expected structure, the Thai building code allows for a permit-free realization if specific criteria are met (Vacharaprechaskul, 2015). Relevant restrictions are components with a length of no more than 4 m, foundation piles with a depth of no more than 6 m, a total net area of no more than 150 m², and a building height of less than 4 m.

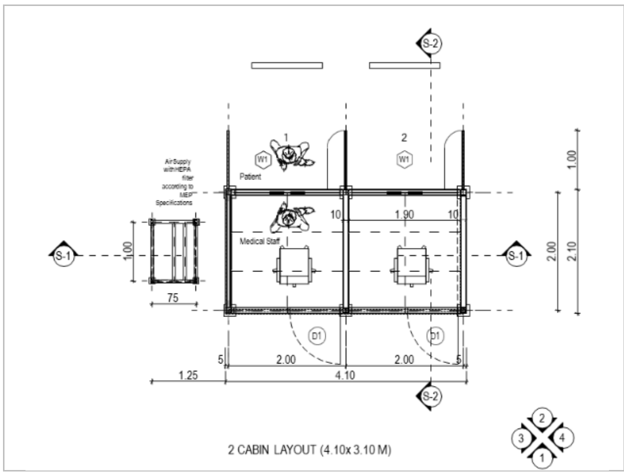
Transportation: The screening station requires its main building structure to be suitably dimensioned to enable transport. A suitable dimension for placing the station on the platform of a medium-sized truck limits its dimensions to 2.2 x 6.0 x 4.0 meters (Tangchaitrong, 2020). Any extensions that exceed these dimensions should be removed for transport. For adequate loading of a truck, the integration of crane hooks should be considered part of the design. Weight restrictions for lifting truck cranes, typically around 1.5 tons in a short reach (less than 5 m) work area, can also be considered.

3.3 Prototype Design, Testing, and PIR

The research also provides for the construction of a prototype of a screening station with two cabins (or two modules) to carry out the PUI consultation and the sample taking for testing, to enable a later review of the implementation of the operation as well as assessment of the construction process, assembly/disassembly and of transportation. The prototype is fully functional and intended for use in an outdoor area near a health facility in Thailand. With the prototype design pre-assembled in the workshop, operational tests were conducted to determine whether the expected design was appropriately functional for its use. The tests included a test run of the air conditioning system to measure air temperature, humidity, and air pressure in the cabin via installed monitoring devices—furthermore, the implementation of a standard operating procedure for the performance of sampling. After the screening station's transportation to a hospital and on-site installation, the post-implementation review was executed to determine whether the COVID-19 screening station project successfully produced the anticipated deliverables for operation and maintenance.

4. Result

The prototype screening station's design result, construction completion, transportation, and installation on the predestined site are described in the following. It also includes a summary of a post-implementation interview conducted with the COVID-19 screening station contractor. Some of the significant design and planning features are shown in ผิดพลาด! ไม่พบแหล่งการอ้างอิง and 2 showcasing floorplan and section as drawing documentation example.



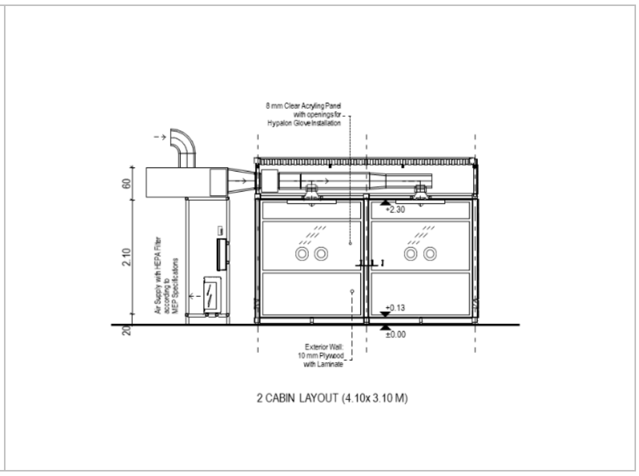


Figure 1: Left: Floor Plan of Screening Station Prototype

Figure 2: Right: Longitudinal Section of Screening Station Prototype

Considering the needed circulation space in front and behind the screening station, a corridor space of 1 to 1.5 meters should be provided. Waiting areas for PUI can be arranged nearby with the considerable distance (1.5 meters or more) between individuals upheld. These areas are also sufficient during installation when the modules are placed using shunting equipment such as forklifts or dollies.

The design solution provides layout arrangements of varying sizes through combination through its modular design of units. These cabins offer the spatial separation between PUI and the operative HCW, allowing them to work from an isolated space to examine and treat patients in its front. If necessary, sampling can be realized via sealed gloves installed in the cabin window. With positive air pressure and HEPA air filtering, the air conditioning system achieves the objective of making the facility safe for HCW. Measurements in the cabins showed that positive air pressure could be built up and maintained quickly over time, reducing the need for extensive use of PPE. Natural ventilation outdoors is another effort to avoid possible human-to-human infections between PUI. Partition walls that are easy to clean further support such. With a steel frame structure, the screening station is suitable for road transportation purposes. By removing external elements such as the roof, air conditioning system, and partition wall of the stations and later reinstalling on-site, the outer dimension enables lifting onto flatbed trucks.

Considering locations for installing the screening station, the station's flexible, adaptive usage allows for mobile use and set up at remote off-premises areas where electric infrastructure exists. The air handling units currently projected can serve up to four cabin modules in total, which increases maintenance and initial costs somewhat if only two cabins are delivered. The costs for a prefabricated screening station are approx. 450,000 THB, excluding transport and installation on site. Prices are likely to decrease as improvements are considered, e.g., the implementation of reduced cabin size, repetitive manufacturing, and inherent optimization processes.

4.1 Prototype testing, installation,

Figures 3 and 4 show the station's prototype testing at the workshop facility in Nonthaburi. Inside the screening station, the HCW will be operating. The HEPA filtered fresh air supply is pressurized with about 5-pascal positive air pressure to guarantee no contaminated air can infiltrate from outside. In the picture, an outlet flap for air pressure regulation is recognizable on the side of the station, allowing to control and maintain the wanted air pressure of the cabins.


Figure 3: Left: Front View of screening station

Figure 4: Middle: PUI Treatment Area Showing testing of installed gloves to conduct sampling

Figure 5: Right: Screening Station lifted and secured on the truck

The prototype was completed in early May 2020 and delivered the following month to the selected healthcare facility, Loeng Noktha Crown Prince Hospital in Yasothon Province. Figure 5 shows the transport with the station secured on a flatbed truck. The screening station is located at a safe and sufficient distance from the existing healthcare facility. Installed nearby the hospital's acute respiratory infection clinic, the screening station is used for COVID-19 screening and sampling, but also to screen and treat tuberculosis patients. Thus, the station appears flexible for various use and future post-pandemic utilization.

4.2 Post Implementation Survey

The post-implementation review with the operating staff and contractor determined that the COVID-19 screening station project successfully fulfilled the projected deliverables. It also considered lessons learned and possible advancement. Suggestions regarding the practical use of the station are a flexible positioning of the gloves for permitting adjustment to individual human size for better working range or allowing for the anticipation of an eventual change in the station's use such as inoculation of patients. The station's outdoor areas can benefit from providing storage and disposal areas for improving the screening and sampling process. By providing a small operable window between PUI and HCW, needed equipment, test kits, sampling probes, etc., can be passed through when no PUI is standing in front of the cabin. To reduce overall costs, recommendations aiming for design improvement were to optimize interior cabins in terms of dimension. In terms of time management, upfront site preparations can avoid time delays and enable better security during transport and set-up regarding logistics and transportation, such as improved design considerations for effective transport and assembly. Limited accessibility of the site and the need to reinstall building parts on-site were the leading causes of the time lag on site. The prefabrication was not optimal and will likely become more time-efficient through repeated installation. Concerning training for operating the station, an MEP engineer undertook staff instruction for the air conditioning and its HEPA filter system. For avoiding contamination of interior and exterior surfaces, the medical doctor in charge instructed assigned staff on the station's cleaning and disinfection guidelines during use.

5. Conclusion

A modular COVID-19 screening station design was developed based on rationalizing existing solutions and expert consultation for semi-outdoor usage near healthcare facilities in Thailand. A working and fully functional prototype screening station was installed to test operational use and suitability regarding local conditions and budget limitations. Accordingly, the design and resulting prototype for a screening station fulfilled the prospects of improving existing healthcare facilities' needs concerning practical use, air handling, maintenance, and cost considerations. Above all, its separation from main healthcare facilities, operating at locations nearby, avoids unnecessary infection of others while providing efficient physical distance between PUI and the treating HCW. Thus, the screening station enables the proper conduct regarding examinations and sampling taking while ensuring a sufficiently safe work environment and avoiding the extensive need for PPE. Based on PIR results, the current prototype solution is adequately planned, including recognizing made comments for improving the station from contractor and existing operator. Future research may further optimize the design of the screening station, focusing on projecting a detailed standard operating procedure and a related inclusive communication graphics with PUI.

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