SOLUTIONS LAB FINAL PROJECT REPORT – EXPERIMENTATION PROJECT

PROVIDING DISASTER RELIEF: HAZE EMERGENCY KIT PHASE ONE

CONTEXT

The 2015 haze crisis, resulting from massive forest fires, affected more than 28 million people mainly in Sumatra and Kalimantan alone.[1] In Palangka Raya, Central Kalimantan, the air quality index level (Indeks Standar Pencemar Udara or ISPU) was recorded as high as 1889, six times the hazardous level as specified by the National Meteorology and Geophysics Agency (BMKG)[2]. The above mentioned ISPU is based on particulate matter with a diameter of 10 microns or PM_{10}. According to the World Health Organization (WHO), particulate matter affects more people than any other air pollutant. Particulate matter which has a diameter of 10 microns or less are the most damaging to people's health because the particles penetrate and lodge deep inside the lungs. Chronic exposure to this kind of particulate matter has been found to contribute to the risk of developing cardiovascular and respiratory diseases, as well as lung cancer.[3]

Most people living in the areas affected by the haze did not have sufficient means of protecting themselves from this health hazard and were forced to breathe in dangerous air. There were over 140,000 documented cases of respiratory illnesses in 2015 alone.[4] The health response to the toxic haze from government and civil society organizations focused on distributing masks, providing 'oxygen houses' with tanks of clean air, haze-proofing schools and turning them into haze shelters, as well as providing medical treatment for haze-related illnesses.

At the household level, air purifier units became a readily available option to protect family members from the toxic particulate matter but with a prohibitively high starting price of US$120. At this cost these air purifiers are not appropriate for last mile communities and are also typically built to combat urban air pollution.

There is a lower cost purifier available on the market - the SmartAir purifier but there is an absence of documented evidence for its usage in extreme haze conditions.

While the 2015 haze crisis was particularly consequential, haze is experienced in Indonesia every year. Kopernik seeks to provide tools for affected populations to be able to protect themselves. This experiment with haze emergency kits targets three design criteria; adoption can be scaled quickly and efficiently, is complementary to household habits and living conditions and low cost (maximum US$50 per kit). The kit is made up of three components

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1 *"Indonesia needs better aircraft for water-bombing operations". The Straits Times. 07 October 2015.*
2 *"Hari Ini Palangka Raya Capai Indeks Pencemaran Udara Terburuk". Republika News. 16 October 2015*
3 *"Ambient (outdoor) air quality and health". World Health Organization Fact Sheets. Updated September 2016.*
4 *"Southeast Asia's Hazardous Haze". Al Jazeera News. 07 October 2015*

(shown in Figure 1):

1. A Fan-Filter Unit (FFU);
2. Materials to seal a room and prevent air leakage; and
3. A three-month supply of 3M N95 Particulate Masks.

Figure 1. The proposed Haze Emergency Kit

The Haze Emergency Kit experimentation project is part of a bigger collaboration initiative called "Grassroots Solutions for Haze Impact" with UNICEF Indonesia, Pulse Lab Jakarta, Ranu Welum, Big Red Button, and MDMC. This initiative has also been supported by the authorities from Palangka Raya's local government, the Ministry of Health, the National Environment Agency, the National Meteorology Agency and by the private sector.

LOCATION

HYPOTHESIS

Our hypotheses were, that:

1. In a closed room, the FFU would reduce the $PM_{2.5}$ level from hazardous to the initial room levels (which were within the safe level of 0-50⌈g/m^3) in a shorter period of time compared to when no measures were taken;
2. The sealing measures provided in the safe room toolkit would reduce the air leakage rate for both types of dwellings. The first type, a wooden house, commonly exists in rural or peri-urban settings while the second type, a concrete, or *beton* house, can mostly be found in cities.
3. The locally assembled FFU would be cheaper and work as effectively as the SmartAir FFU. The locally assembled FFU consists of a standard fan and a filter which was sourced separately in Bali. The components were then self-assembled and modified into a purifier.

We predicted that these haze emergency kits would reduce people's exposure to harmful particulate matters ($PM_{2.5}$ and hence, as discussed above, also PM_{10}) during the haze period based on the working principles shown in Figure 2. We hypothesized that when haze occurs, the toxic air infiltrating the home through various gaps will mean that the indoor air eventually becomes as toxic as the outdoor air. We further hypothesized that the safe room toolkit would enable families to seal the gaps, slowing down the haze entering the room, enabling the FFU to remove particulate matter more effectively and eventually purify the air inside the room.

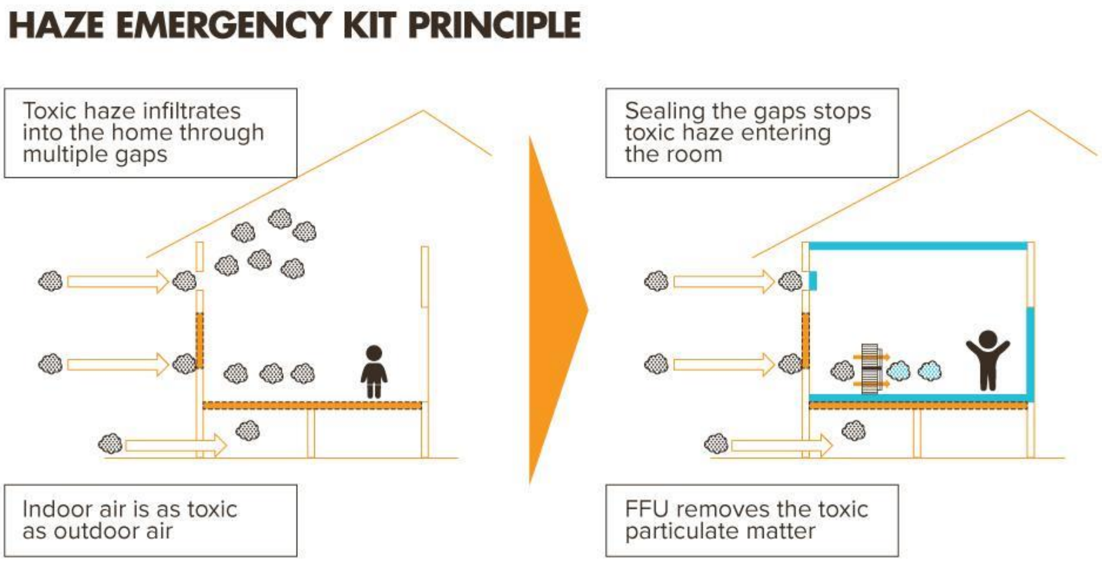

Figure 2. Haze Emergency Kit working principles

METHODOLOGY

A series of tests were conducted at two sites; the preliminary tests in Kopernik's Office in Ubud and the field tests in Palangka Raya, Central Kalimantan. To measure the FFU performance, heavy smoke was generated inside a closed room by burning paper, tissues and wood in a cook stove. A particle counter device, the Dylos DC1100 Pro Air Quality Monitor, was used to detect and to measure $PM_{2.5}$. Monitoring was done continuously throughout the test using a remote webcam placed in front of the particle counter device for 2.5-3 hours.

The general procedure for each test is summarized as:

1. The $PM_{2.5}$ level in the room is measured for 10-15 minutes and the average value is recorded as the "initial room level".
2. The cookstove is lit and after a few seconds heavy smoke is generated and the stove is placed in the center of the room. With the room closed, the $PM_{2.5}$ level is monitored continuously until it reaches a hazardous level (i.e. above 300 $\mu g/m^3$) or 10 minutes of burn time has passed.
3. At this point the cookstove is taken from the room and the FFU is turned on.
4. The $PM_{2.5}$ level inside the room is monitored and recorded as a time-series for the next 2.5-3 hours.

The preliminary test measured the FFU's performance in removing the smoke to $PM_{2.5}$ level. All tests took place in Kopernik's 30m³ office garage. Ventilation holes were sealed wherever possible and the garage roller door was kept closed. Three separate test scenarios were performed; 1) with no FFU 2) with the SmartAir FFU and 3) with the locally sourced version of FFU. Figure 3 illustrates the preliminary test procedures in the garage.

Figure 3. Preliminary test setup. a) Devices arranged in the garage. b) Dylos particle counter to measure $PM_{2.5}$ level. c) Cookstove with paper, wood and tissue as fuel for smoke source. d) Continuous remote monitoring during the tests

The field test was conducted in Palangka Raya to measure the effectiveness of sealing the gaps in two different types of dwellings. For this field experiment, living rooms of 28m³ and 56m³ were selected as test sites for the wooden house and the beton house respectively. The wooden house was located in Petuk Katimpun, a small village located one hour's drive from Palangka Raya city, while the beton house was in Palangka Raya city. Prior to the test, the air gaps such as ventilation spaces or holes were identified in the two houses and were subsequently sealed using the safe room toolkit wherever possible. Figure 4 depicts the field test carried out in the two housing types.

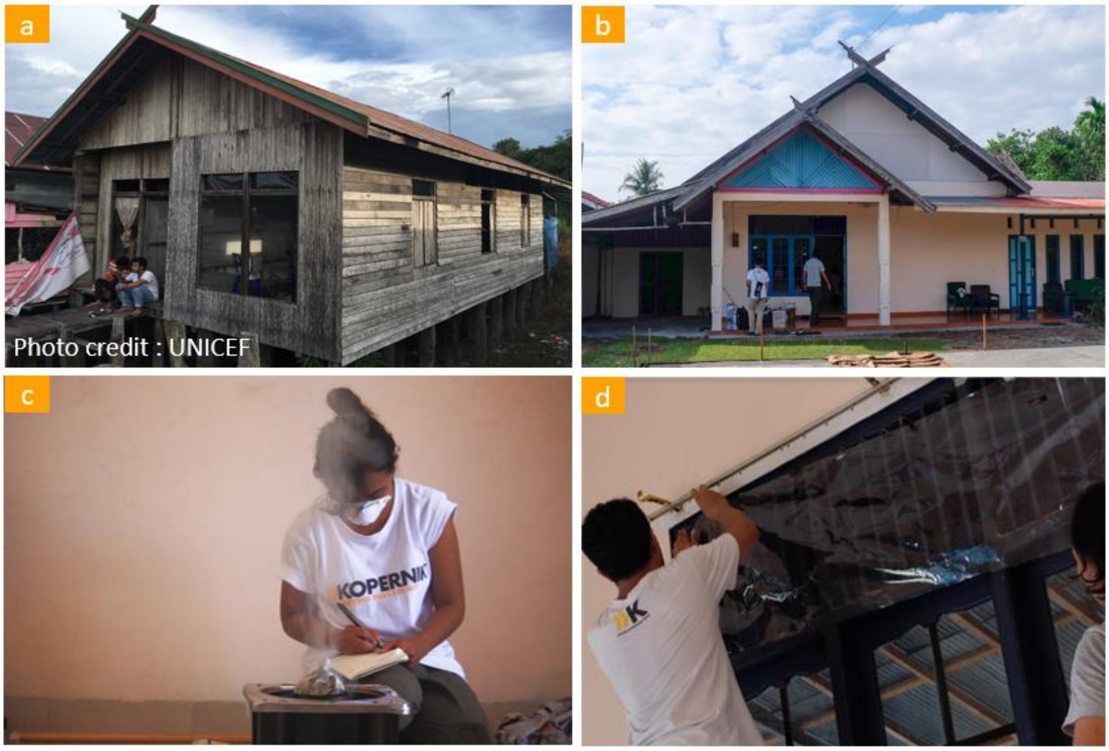

Figure 4. Field tests carried out in two types of houses. a) First test site in a wooden house in Petuk Katimpun village. b) Second test site in a beton house in Palangka Raya city. c) Smoke generated from burning fuel in a cookstove. d) Sealing ventilation spaces in a beton house.

The test methodology was carried out in a similar way as the preliminary tests. In addition, the measurements in the *beton* house was jointly conducted with BMKG where a more advanced air quality monitor, the HAZ-DUST EPAM 4500, was brought over from Jakarta to measure the ambient air quality level. The two monitoring devices were stationed side by side and their $PM_{2.5}$ readings were subsequently compared.

FINDINGS

Performance of the Fan-Filter Unit

Based on the preliminary tests, the recorded time-series of $PM_{2.5}$ levels were plotted and compared for each test scenario (see Figure 5). The graphs suggest that both FFUs were able to restore the initial condition of the room, removing 100% of particulate matter (which had resulted from burning the tissues, paper and wood) within one hour and 25 minutes. In the same amount of time, with a similar test conducted in the same room without the FFU unit, 21% of particulate matter dissipated. Based on this round of testing, it can be said that the FFU works five times more effectively than when no measures were taken. In the field tests, due to time and resource limitations and frequent blackouts, the results achieved were not conclusive regarding the FFU performance in the two houses in Palangka Raya. We would suggest further tests for the test scenarios. Energy stability will also need to be a consideration for the final recommendations for the kit.

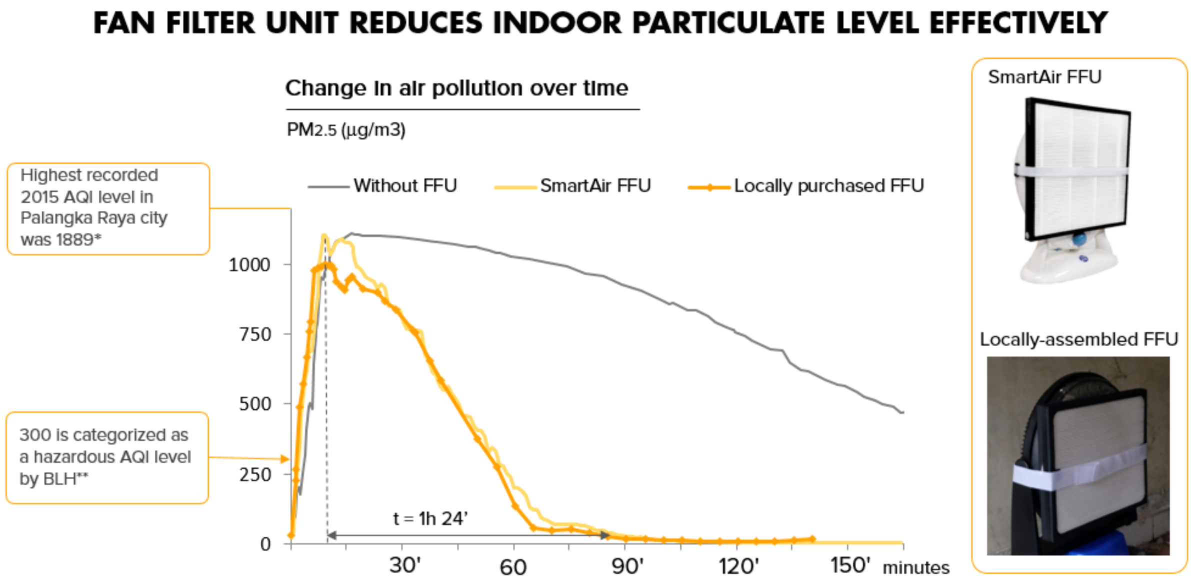

*Figure 5. Recorded time-series of $PM_{2.5}$ level were compared to highlight the results of the three test scenarios. *Data from BMKG's $PM_{2.5}$ reading in Palangka Raya city for 2015. ** BLH (National Environment Agency) used only PM_{10} as Pollution Standard Index*

Another notable finding was that although the local version of the FFU worked as effectively as the commercially ready SmartAir FFU, its total cost was no cheaper. While the SmartAir FFU cost around US$76 (US$35 + US$41 for shipping and taxes), the total cost of the fan and filter purchased from local shops was approximately US$75. Therefore the cost of both FFU's are still above the targeted design criteria of the whole kit (approximately US$50 dollar per kit) The reason is that Kopernik could not procure a filter with the same specifications as SmartAir's HEPA filter manufactured in Indonesia. An imported "BlueAir" branded filter was bought for US$45 and an Indonesian-manufactured "Kris" branded fan for US$30 from Ace Hardware in Bali. The fan still required some modifications.

Effectiveness of the safe room toolkit

In our field test, the sealing process using the safe room toolkit resulted in a reduction of air exit time between indoors and outdoors by three times, both from the wooden house and the *beton* house, as shown in Figure 6. This confirmed two positive outcomes: firstly, the polluted air from the outside infiltrated the house slower; and, secondly, the purified air produced by the FFU did not leak, preserving the safe level inside the room for a longer period of time.

However, the overall cost for purchasing the safe room toolkit for the wooden house was quite high, around US$63. This is due to the high number of identified holes and gaps in the wooden house, such as the open ceiling roof, the cracks in the wooden wall slats and the gaps between the floorboards. In addition to the cost, sealing the room in the wooden house resulted in overheating where the family (whom we interviewed after the test) found it very uncomfortable to stay inside the sealed room for a long time.

In the *beton* house the results were more successful with the cost of sealing the room around US$34 and people finding the temperature comfortable inside the sealed room. The sealing work for the *beton* house also only took one hour while for the wooden house, it took between two to three hours.

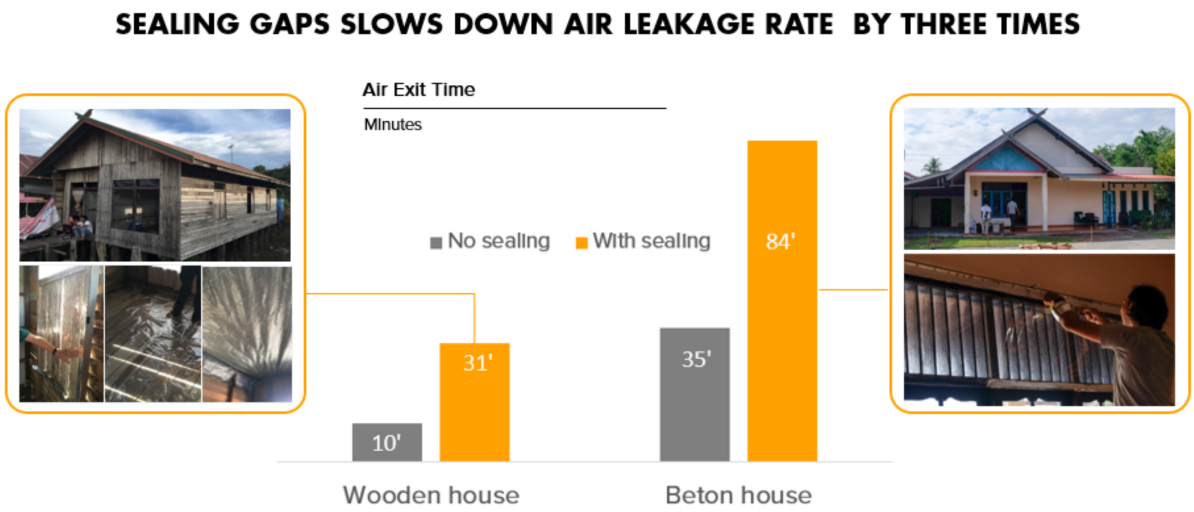

Figure 6. Air exit time after the sealing work takes places in a wooden house and a beton house

Other Findings

During the field tests Kopernik collaborated with several organizations such as Big Red Button (BRB), which has previously piloted haze shelters, and Ranu Welum, which advocates for haze issues in Palangka Raya. BRB has been developing a small-scale shelter suitable for family use. The Nest, is a self-build structure made from rattan with a FFU fitted in its roof. This structure purifies the air and at the same time regulates the heat within the unit with gravity pressure flow. Figure 7 shows the first prototype of the Nest.

Figure 7. First prototype of Haze Nest by Big Red Button

With BRB's permission, Kopernik conducted a quick test to measure the effectiveness of the

Nest and the results were promising. We lightly smoked a $100m^3$ room after sealing it in the same manner as the previous tests. Outside the Nest the emission reading of $PM_{2.5}$ was $200 \mu g/m^3$, which were twice the levels inside at $82 \mu g/m^3$. After the FFU was turned on, the $PM_{2.5}$ continued to drop until $50 \mu g/m^3$. This indicated that the Nest was capable of a significant reduction of pollution level. Unfortunately, due to limited resources, Kopernik could not conduct further tests to see how much time was required for this system to completely purify the air.

CONCLUSION

Kopernik compared the tested solutions based on the cost, effectiveness and ease of implementation. Table 1 outlines the findings from these tests:

	Fan Filter Unit		Sealing works	
	Smart Air	Locally Assembled	Wooden House	Beton house
Effectiveness compared to no measures being taken	5 x more effective*	5 x more effective*	3 x more effective**	3 x more effective**
Cost	$35 (+$41 dollar shipping cost)	$75	$63	$34
Ease of Implementation	Very easy	Needs modifications	2-3 hours work	1 hour's work
Side-effect	-	-	Over-heated room	-

*Table 1. Summary of solutions tested and our findings. *effectiveness in reducing $PM_{2.5}$ level. ** effectiveness in preventing air leakage*

Referring back to our hypotheses on the first page we concluded that:

a) The test results successfully proved that both FFUs were able to reduce the $PM_{2.5}$ level, from hazardous to the initial room level within one hour 25 minutes, five times faster than when no measures were taken;
b) The test results successfully proved that safe room measures were able to reduce the air leakage rate for both types of housing by three times. However there is a negative side-effect of the safe room measure for the wooden house as the room became overheated and uncomfortable for resident to stay inside. Furthermore, the cost to seal a room in the wooden house was relatively high.
c) The experiment disproved our third hypothesis, since we found that the locally assembled FFU is as expensive as the SmartAir FFU, although it did work as effectively.

The overall experiment concluded that the haze emergency kit effectively reduces the $PM_{2.5}$ to a safe level, and is a promising solution for a *beton* house. For a wooden house, we concluded that the safe room measure was too costly and not a good fit due to overheating. Kopernik concludes that the Nest may be an alternative solution, however further tests need to be conducted to properly assess its viability. Although the SmartAir filter is the cheaper option compared to the locally purchased FFU, the lead time for ordering a SmartAir filter from China is around one month, making it not the most suitable solution for an 'emergency' kit.

TESTIMONIAL :

"Air pollution is a leading factor in the deaths of children under five and UNICEF Indonesia is taking action to reduce the impacts of the toxic haze from land and forest fires in Indonesia. UNICEF Indonesia has been working with Kopernik on rapid prototype testing. As a partner, Kopernik are dynamic, collaborative and focused in their approach of evidence-based product design, testing and innovation. When Kopernik commits, they deliver results. I look forward to the prospect of working with Kopernik on next level project stages and new initiatives to serve last mile communities"

- Richard Wecker, Risk Reduction Specialist, UNICEF Indonesia

RECOMMENDATIONS

Based on the data collected, we recommend that:

1. Kopernik, in collaboration with other organizations, tests the 'Nest' and works on improving the design and assessing its viability as an open-source solution;
2. Kopernik, in collaboration with other organizations, keeps sourcing and testing local versions of FFU that can match the performance and the actual cost of the SmartAir FFU;
3. Kopernik, in collaboration with other organizations, continues refining the minimum viable products for the haze emergency kit prototype;
4. Kopernik, in collaboration with other organizations, tests the viability of a large scale haze emergency kit for schools.

LEARN MORE

More information is provided about the Haze Emergency Kit's prototyping work in the following documents:

"GLF Digital Summit: Fires, haze and health – applied research, collaborative design and prototype development". Global Landscape Forum. October 2017

"Haze-proofing in Indonesian Borneo". UNICEF Indonesia Blog. 28 August 2017.

More information is provided about the collaboration of the Grassroots Solutions for Haze Impact in Indonesia in the following documents:

"Post-event follow-up: Peatlands matter, but what are we actually doing about fire and haze?". Global Landscape Forum. July 2017.

"BNF supports grassroot solutions to haze problem in Indonesia". Borneo Nature Foundation. 18 July 2017.