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The Life Tube: A fire emergency design

Danwei Ye

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The Life Tube:
A fire emergency design

A thesis submitted to the Faculty of the College of Imaging Arts and Sciences in candidacy for the degree of Master of Fine Art in Industrial Design by

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Spring 2015
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Abstract

The Life Tube is a thesis design concerning a fire emergency self-rescue kit. It can be deployed into a regular fluorescent light system. When a fire occurs, the Life Tube automatically drops the needed supplies for occupant escape, including a directional light, toxic gas filter, and oxygen mask.

In this paper, I will state the problem of current fire emergency products and the development of my solution, a fluorescent lamp replacement concept. Also included herein is the process of the design, from ideation to working model, as well as the process of setting up the thesis show and graphics.
Introduction

I. Problem statement

Each year, more than 4,500 people die and 22,600\(^{[1]}\) are injured in fires in the United States. Even given properly installed fire alarm systems and the rescue efforts of fire fighters, people run a very real risk of dying from the extreme conditions in a burning building.

Hot, toxic gases and smoke from fire are typically more dangerous than the flames themselves. Inhaling the super-hot air can sear people’s lungs instantly. Fire produces poisonous gases that cause people to rapidly become disoriented and drowsy. Asphyxiation is the leading cause of fire deaths, exceeding burns by a three-to-one ratio.

Additionally, when a fire occurs, the whole building will frequently lose electrical power and thus illumination, making safe egress very difficult if not impossible given the smoky conditions.

In order for the escape solution to be useful, when a fire occurs, people need to be able to quickly find and deploy it, and not need extensive training to do so. Sadly, it is frequently the case that people are unable to find or use self-rescue supplies. Even in a home dwelling scenario, where people have made a personal commitment to purchase and use a rescue kit, the lack of its use in daily life will mean that the owners gradually lose familiarity with the kit location and usage. In time the kit effectively becomes useless as it inevitably gets shuffled about the home and eventually stored in a location difficult to remember (or reach) in case of a fire.
II. Thesis statement

This thesis design will consist of a new product that can save life by offering just those needed emergency supplies to enable rapid fire egress. To my point of view, the main problem to be solved is the hazard of the smoke/toxic gas, combined with being unable to find an exit route.

In my design, I have endeavored to combine the functionality of an emergency oxygen mask with a commercial illumination system that doubles as a flashlight in an emergency. The thesis design output is a fire emergency self-rescue kit. It will act as an exact fit replacement of a standard (T8) fluorescent lamp. In daily use, it will produce the same amount of light (lumens) with the same or less electrical power consumption of a standard fluorescent tube. When an emergency occurs, it will automatically drop the flashlight/gas mask pods. The system will be designed to seamlessly integrate into a multi-story apartment building, office building, or any other kind of high-rise.
Survey of Literature

I. From reference books and website papers

Given normal activity, an adult consumes 1.84 lb. of oxygen per day\(^2\), thus 0.2 lb. of oxygen is more than enough for 1 hour escaping time. Therefore, it is theoretically possible to store enough oxygen in a relatively small device for a 15 minute fire egress.

Moreover, Researchers from the University of Southern Denmark have synthesized crystalline materials that can bind and store oxygen in high concentrations. The stored oxygen can be released again when and where it is needed.

By using this material, the device will be able to release the stored oxygen in a controlled manner when it is needed.

An important aspect of this new material is that it does not react irreversibly with oxygen. The material can be used to bind, store, and transport oxygen, much like a solid artificial hemoglobin. Varying the composition of the material affects the bind and release rates of oxygen, allowing for a tuning of its properties.

Even more interestingly, the material may also be configured in a device that could absorb oxygen directly from air that is low in oxygen. So it could store and release oxygen, meanwhile produce oxygen from the air in a fire environment even the oxygen level is low.

To sum up, considering the oxygen needs for a normal adult human, and assuming the successful commercial development of the new material, the oxygen generation device could potentially be small enough to deploy into a handheld device.
II. From online resources

There are many standard fire emergency devices, and codes applied to building construction. I performed an online research about major fire emergency products, the results of which is listed below:

(1) Fire emergency lights

![Regular fire exit light and alarm](image)

Fire emergency exit lights are self-contained systems that are wired to the building electrical mains but which have a battery back-up to ensure that the lights provide illumination even when the main power supply is interrupted. These lighting systems are used to illuminate emergency exits.

Emergency lighting systems are required by law to be used in virtually all commercial and high raised residential buildings. Their primary purpose is to illuminate fire exits during an emergency. There are also emergency lighting systems on commercial aircraft that illuminate emergency exits and illuminate a path to the exit(s).

There are two main types of emergency lighting: maintained systems and non-maintained systems. Maintained systems are continuously lit (regardless of whether the status is normal or emergent) and required by law for areas with low lighting. According to Neweysonline.co.uk, maintained systems are used for "cinemas, theatres and anywhere alcohol is served". Non-
maintained systems are lit only when the main power supply has failed. Typically these non-maintained systems as used in stairwells and corridors to allow for safe exit by occupants.

(2) Fire emergency signs

Figure 2 Emergency exit sign

Easy-to-read Emergency Exit signs clearly identify this key area for workers, visitors and emergency personnel. They can also discourage use of unauthorized exits at other times.

(3) Fire emergency alarm system

Figure 3 Emergency alarm trigger

An automatic fire alarm system is designed to detect the presence of fire by monitoring environmental changes
associated with uncontrolled combustion. In general, a fire alarm system is classified as either automatically actuated, manually actuated, or both.

Fire alarm systems are intended to notify the building occupants to evacuate in the event of a fire or other emergency, report the event to an off-premises location in order to summon emergency services, and to prepare the structure and associated systems to control the spread of fire and smoke (e.g. by the closing of dampers within the HVAC ducting).

(4) Fire Protection Systems

Fire protection systems are those systems put in place to prevent or mitigate the unwanted effects of fire.

![Fire Sprinkler](image)

**Figure 4 Fire sprinkler**

Wet Fire Sprinkler System is the fire protection system that is most often installed. The wet fire sprinkler system is very simple: it has a sprinkler nozzle and a heat deformable plug. When the wet fire sprinkler is exposed to heat beyond a certain temperature, the built-in heat sensitive plug will melt or yield, falling out and allowing water to flow from the sprinkler nozzle. There are two basic types of fire sprinkler systems: one supplies water when needed, while the other is continuously pressurized. The system with pressurized water has distinct disadvantages.
The water inside the pipes can quickly become stagnant, and a breeding ground for bacteria and mold. The water can also freeze and break the pipes; this is why regular draining and refilling of the pipes is necessary.

Dry pipe systems are used in areas where cold is a factor. This system eliminates the storage of water, such as in a wet pipe system, in order to prevent the water from freezing. This is necessary in places that do not have heating, such as parking garages, attics and temporary out-buildings. In the dry pipe system, pressurized nitrogen is stored in the piping system instead of water. The nitrogen is released when one or more of the sprinklers' fusible plugs melt, permitting the water to flow. The main disadvantage of a dry pipe system is the delayed response when there is a fire, as the water must first displace all of the nitrogen before it can flow out, just like the case of an empty hose.

Pre-action systems employ the basic concept of a dry pipe system in that water is not normally contained within the pipes. The difference, however, is that water is held from piping by an electrically controlled valve rather than by a balancing gas pressure. Valve operation is controlled by independent flame,
heat, or smoke detection. There are three types of pre-action systems: the Single-Interlocked Pre-action system allows water to flow into the closed sprinkler system upon the activation of a detection system. In the case of the pre-action system, it is the pre-action valve which keeps the water out of the pipes. The pre-action valve is held closed electrically to be released only when the detection system is activated. The detection system could be a heat or smoke detection system. When this happens, water fills the pipes to be released by the sprinkler. The Double-Interlocked pre-action system does not allow water to flow into the pipes until both the detection system and the sprinkler system are both activated. This is to prevent the accidental discharge of water. The Non-Interlocked pre-action system will allow water to flow into the pipes when either the detection system or sprinkler system is activated.

(5) Fire emergency kit/ Burn kit

![Regular burn kit](image)

Figure 6 Regular burn kit

Burn kit includes the basic necessities for burn care. Products are often contained in a sturdy, reusable plastic (or steel) case sealed with a gasket.
Fire blanket is fire retardant due to its DuPont X-12 treatment. They often come with 4 mounting brass grommet holes to attach below fire emergency kit cabinet.

(6) Emergency mask
Firefighters wear a positive-pressure mask with speaker module. Positive pressure means that air is always flowing, whether the wearer is inhaling or not. The positive (gauge) pressure keeps contaminants from entering past the face seal at the sides. The speaker module electronically amplifies the wearer's voice, and can be connected directly to the radio so that no handheld microphone is necessary.

An Air Purifying Respirator (APR) is worn when conditions are not so severe as to require a full SCBA (Self Contained Breathing Apparatus), which is much heavier than a respirator to wear. Unlike SCBAs, APR masks have no tanks or hoses. APR masks are used as particulate filters, but because they do not supply air, they are only used after the atmosphere has been tested as containing enough oxygen to support life. This is usually after a fire, during the salvage and overhaul phase. Usually worn with a particle filter, these masks can often be used with a special cartridge (CBRN) for protection against Weapons of Mass Destruction agents.

Relative Effectiveness of Mask Protection

<table>
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<th>Mask Type</th>
<th>Effectiveness</th>
</tr>
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<tr>
<td>No mask</td>
<td>1</td>
</tr>
<tr>
<td>Paper mask</td>
<td>10</td>
</tr>
<tr>
<td>APR</td>
<td>100</td>
</tr>
<tr>
<td>SCBA</td>
<td>10,000</td>
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As the chart shows, SCBAs are by far the most effective protection, and would be worn under all conditions if they didn't weigh so much.
This concept respirator was designed by Jason Swartzentruber (and featured on the concept technology website Tuvie.com). It contains such advanced features as a GPS tracker, a rotating cylinder harness, and a voice amplifier, which are designed to make firefighters safer and more effective at their work.
III. From professionals

The West Brighton Fire Protection District (Figure 10) is one of two Fire Districts within the Town of Brighton. The WBFPD covers the west-side of the Town of Brighton. Its boundaries are Brighton-Henrietta Town Line Road and Jefferson Road to the south, East River Road to the west and north, and South Winton Road to the east. During my visit to West Brighton Fire Department, I had a chance to talk to the line firefighters.

I spoke with the Line officers and showed them the Life Tube concept. All of the lieutenants expressed different points of view. In summary, they liked the concept a lot, and they believed that if certain problems could be solved, the Life Tube design could eventually become standard equipment for new residential and commercial buildings. The major problems they stated are listed below:

(1) Occupant Panic.

Victims during extreme conditions often become emotionally unstable, making them incapable of effectively using their higher
cognitive reasoning abilities. Therefore to make the device easy and intuitive to use, and easily accessible would be essential.

(2) Oxygen safety

The container inside the device must carry the oxygen in a safe way. They expressed a preference for generating oxygen using chemical reactions rather than storing elemental oxygen. They expressed the caveat however that the generation reaction should not be done using high temperatures or by single-substance decomposition.

(3) Quantity

The quantity of the Life tube devices should be sufficient for all building occupants. To reduce the possibility of a scramble/stampede the device should be evenly distributed and made available to all major spaces.

(4) Education

Education is essential to ensure that the retrieval and donning procedure will be correctly performed by the general public. Although the design's operation itself is not hard to decode, people may still have a hard time to use it in emergent conditions owing to psychological pressures. An introduction lesson should be conducted periodically within all office buildings equipped with the Life Tube. Within Life Tube equipped buildings, there should be educational materials posted within such locations as the main entrance, major corridors, elevators, etc.
Design perspective

After referencing all the information from online and onsite research. To make sure the design procedure be guided within certain rules, the following perspectives will apply.

I. Empowerment of the product

(1) Advertisements and posters and office area education.

There should be educational video clips available online. In addition, it would be a good idea to periodically play a Life Tube PSA on public screens to draw people’s attention to the proper usage of the product. Within the buildings lacking ad screens, posters about the product should be posted. To make people confident about the product, there could be some special facts and specs about the product on the poster. For office areas, all employees could receive education by certain informational sessions or advertisements of the system via their work computer’s screensaver or booting screen.

(2) User diagram on the entrance.

The method of use for the new device is unique, thus it would be helpful if people could learn the proper use procedure during times of transit and waiting in the building. Thus, the application of an instructional sticker in public spaces such as the elevator would important for this concept.
II. System specs and installation

(1) The design concept should allow for the packaging of a multiple modules per light fixture, so as to serve as many people as possible.

During a fire, people will panic. To prevent occupant casualties, there should be enough units deployed: at a minimum equaling, but better yet exceeding, the occupancy of the building.

(2) The design concept should be a direct retrofit substitute or complementor of the current fire alarm system.

Substitution is better for commercial organization than deploying brand new system, so the design should be able to substitute current emergency systems or as an easily installed new attachment to the old system.

(3) The design concept should have proper performance.

By proper performance, it is meant that the design needs to be qualified in both regular and emergency scenarios. For normal use, the design should function as good as the original light source it substitutes. For emergency, it should have capabilities to provide necessary support.
Design progress

I. Ideation

(1) Concept A

Concept A is a substitution for a regular ceiling light. When not in use, the device acts as a regular ceiling light. When an emergency occurs, the mask drops from the ceiling, and people can grab it easily. The mask has a carbon monoxide/toxic gas filter system and an internal battery which keeps the light on for hours. Additionally, it should have a small oxygen tank in the mask that stores at least 4oz of oxygen.

Figure 11 Concept A
As seen in Figure 12, the mask is connected to the dropping wire by magnetic contacts, and contains a LED light system and an oxygen tank.
Figure 13 shows that when the system is inactive, the mask acts as a regular ceiling light.

Figure 14 shows when the mask dropped to within reach height.
(2) Concept B

Concept B is a substitution of sidewalk night light. The detachable device would have three built-in LED lights and a filter/oxygen generation system. When an emergency occurs, the device ejects from the housing for use. The user then would put it in his/her mouth to activate the filter/oxygen generator.

As seen in Figure 15, concept B provides a way to deploy the mask at a lower height as well as providing a warning sign light for escape. This design is especially useful when people are crawling on the floor during fire emergencies.
(3) Concept C

Concept C is a form factor and function substitute for a standard (T5 or T8) fluorescent tube. It contains multiple pods, assembled in a package sized similar to regular fluorescent lamp. It can be deployed into a regular light system as a replacement for fluorescent lamp. When not in use, it can produce same amount of light with less power consumption. When emergency occurs, it automatically drops the pods, which contains needed fire emergency supplies such as a flashlight and oxygen/filter mask.

Figure 16 Concept C

As seen in Figure 16, concept C provides a way to deploy more masks at a greater numerical density than the other concepts. Considering that the majority of fire emergency scenarios occur in a crowded environment, this concept will be best able to solve the quantity issues this system design may encounter.
II. Development of concept

Concept C is a solid concept to deploy to current system and it could provide sufficient units when an emergency occurs. The next steps will be developed based on concept C.

The overall system contains pod units, housing for pods, control hub, and other structure components to fix the pods in place.

(1) Pods-Light system

The pod units of the Life Tube system are made by ABS plastic, as it is durable and has suitable temperature range.

Two LEDs are used as the illumination sources. One of them will be used for emergency situations, as a flashlight powered by a Li-ion battery at one of the ends. While standing by, both LEDs will illuminate, providing 600 lm(Lumens, a measure of the total amount of visible light emitted by a source) of a white/yellow light, equivalent in intensity to a standard fluorescent lamp of the same length.

Figure 17 Two LEDs light source
As stated previously, combustion by-product gases and smoke from a fire are typically more dangerous than the flames. The Life Tube has a filtration system at the end opposite to the battery. It contains an oxygen generator and an activated carbon filter to protect user from chlorine, carbon-monoxide, and other toxic gases.

(2) Pods-Filter system

Figure 18 battery and electric board inside

Figure 19 Mouth piece
When standing by, the filtration system is sealed for preservation. When an emergency occurs, it will deploy the vent system while dropping, and, as a trigger, when the user pulls out the mouthpiece, it will become fully functional.

(3) Housing

Because each pod measures 5 inch in length, it can be deployed into different case lengths by changing the dimension of the bar transformer. While in the housing case, pods line up in a connection like batteries.

When replacement of fluorescent light is not an option, The Life Tube can also be deployed into a specially designed case.

Special designed rails keep pods in a specific orientation. Cords could be coiled back to the main body while reloading the pods after the hazard. The pods are designed to be snapped back into their original place.
III. Internal design

The internal structure of The Life Tube contains four main systems: Extendable mouthpiece, air filter and oxygen generator system, battery and charging system, and lighting system.

(1) Mouthpiece. The mouthpiece is made of plastic, and it has a rubber coating at the bottom end to seal the airway.

(2) Air filter and oxygen generator. The air filter is made of high density activated carbon, which absorbs toxic gases. Oxygen generator tank contains 2oz of a solid state oxygen absorber, it will triggered by pulling out the mouthpiece and slowly release oxygen into filtered air.

(3) Battery and charger. The pod use a regular 16340 battery as power source, and connected to both ends of the pod.

(4) Lighting system. Two 3 watt LEDs are used as the light source.

(5) The control chip in each tube contains a radio communication system that connected to the main control system to transfer signals. (not illustrated)
While in the case, pods line up in series connection just like batteries.

Mouthpiece

Rubber seal

Oxygen has an expansion ratio of 1:801. So a small tank of oxygen is enough for a building escape.

Battery unit

ABS L-cap

Rechargeable battery

Internal Li-ion battery will recharge when needed and this kind of battery could keep flash for 10+ years.

Also interchangeable with 18650 Li-ion battery.

Water filter system

Aluminum heat sink

LED light unit

Diffuser

6W LED Component

LED is a great lighting source because it has higher energy efficiency, longer life and lower temperatures, also small in size.

Figure 22 internal structure design mockup
IV. Physical model/Mockup model

Figure 23 Main body and LED diffuser

Figure 24 LED module and heat sink
Figure 25 structural material

Figure 26 Assembled pod unit
User scenario

I. Act as regular light

When in regular setting, The Life Tube acts as a regular light. It fits into extant fluorescent lighting systems, working on converted AC power. Light emitted from LEDs will be equivalent in output intensity (lumens) to a standard fluorescent lamp of the same length.

II. Act as emergency light

When the building experiences a power outage, The Life Tube can automatically turn one of the LEDs on to act as an emergency light. The standard 16340 battery can last for up to 40 min, and an optional extended run 18650 battery can last up to 160min.
III. Act as fire emergency mask

When a fire occurs, The Life Tube will deploy from its case and can be used as an emergency mask. By the support of light & filtration system, the pod would not only light the way to escape but would also filter toxic gas and generate oxygen. The battery and filter can keep fresh for more than 10 years, and due to the modular design of The Life Tube, they could be quickly replaced, making maintenance relatively easy.

Figure 28 Drop mask mode
Thesis exhibition

Setup of the exhibition

Figure 29 Test of the working prototype

Figure 30 Setup for displaying inner structure
Figure 31 Special designed fire alarm trigger (Left) for animation

Figure 32 Dropped pod are complete working model for people to touch
Poster design

Figure 33 Poster one shows the basic design of the pods
Scenarios

Act as regular light
When in regular setting, Lifetube act as a regular light. Because each pod measures 5 inch in length, so it can deployed into different case length standard by changing spacing of bar transformer.

When replacement of fluorescent light is not an option, Lifetube can also be deployed into special designed case.

Act as emergency light
When the building is experiencing power shortage, Lifetube can automatically turn one of the LEDs on and act as emergency light.

Powered by its built-in battery. The standard 16340 battery Lifetube can last for 40min, and an extended 18650 battery can last for 160min longer.

Act as fire emergency mask
When fire emergency occurs, Lifetube will deploy from its case and can be used as an emergency mask. By the support of light & filter system, the pod not only could light up the way to escape but also could filter toxic gas and generate oxygen.

The battery and filter can keep fresh for 10 years, and due to the modular design of Lifetube, they can be replaced quickly. Making the maintenance easier.

Process of making

Figure 34 Poster two shows the scenarios of the working system
Public reactions

Figure 35 Received comments from professors

Figure 36 Student visitor are attracted to the video
Figure 37 visitors are willing to learn about the concept and try the fire alarm
Conclusions

I. Overall

The Life Tube system represents a novel, life-saving fire alarm system complement. It relies upon current technology and mainly COTS (Commercial off-the-shelf) components. It could be easily mass produced at a relatively low cost. For new buildings, it would be a standard emergency egress assist system, requiring no additional space in the built environment. For old building retrofit, it would only require minor, easily performed modifications to the current fire alarm system.

Figure 38 Overall shape (right unit with diffuse cap)
II. Design achievements

The Life Tube design has solved many of the problems that exist with current fire alarm and egress systems. The design provides an oxygen supply, air filtering, and portable emergency light needs. The Life Tube creates a safer environment for buildings by complementing existing fire alarm and egress resources.

Moreover, unlike the transitional emergency kits which may not be used for years, the design of the Life Tube makes it a perfect light system for daily use. The relative ease of performing retrofit upgrade within older structures without occupying any new space would be another major plus.

III. The design solution works well as an add-on module/extension for extant fire alarm systems.

The Life Tube system contains a radio communication system that acts as an extension to the current fire alarm system. A new transceiver module would need to be applied to the current base station system. In turn, each pod stack tube would have its own transceiver. A periodic status check of each pod stack tube within the facility would be initiated by the alarm base-station computer system. The pod stack tube transceiver system would be powered by the on-board Li-ion batteries to prevent power outage condition. Should a pod tube stack fail to detect a base-station signal within a factory-set maximum period, or should it detect a local abnormality (e.g. low backup battery voltage) it would blink the LEDs to independently signal the abnormal status.
IV. No new technology attached, using current/existing technology to achieve.

The concept was developed considering available technology. The LED light source is a mature technology that is energy efficient, has a long life span, and is compact. The Li-ion battery inside the pod is widely available in the market, as well as the air filter. Secure (encrypted) radio communication and control technology is essentially a COTS item.

V. What issue needs to be addressed before hitting the market.

The current design has a spacing bar to change the length of the system, thus it have capabilities to fit any fluorescent fixture. The power connection of the fluorescent bulb is standard socket, so the system would have the same power connector throughout the product range.

The grid-like baffles in a typical fluorescent fixture could block the module from dropping down. To fix this problem, the current baffle would need to be replaced with a baffle on a larger grid dimension, or the lamp assembly baffle itself would need to be dropped prior to Pod deployment under the control of an automated triggering system in the event of a fire occurrence.
Reference

Book/paper


Website