

Article

# An Article on Green Firefighting Equipment in Taiwan

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**Abstract:** This paper discusses the relationship between green buildings and fire safety from a higher perspective including the traditional fire factors, fire resilience, sustainable building SAFR, social, ecological, and economic fields. There is no need to sacrifice fire safety in the name of sustainability. There is no direct report of fire incidents with green design elements. However, indirectly from the characteristics of residents, green buildings have a high degree of intersection with vulnerable groups, which directly affects the life safety of green building fires. The gray water recycling design of sustainable buildings (green buildings) combined with a simple waterway-connected sprinkler system will be an excellent cooperation example between green (Green Design) and red (Fire Safety). Taiwan's photovoltaic development plan is expected to reach the 500 MW in 2025, which is equivalent to 2.5% of the government's promotion target of 20 GW. Whether a PV fire occurs during the day or night, photovoltaic modules will generate lethal electricity, which is a potential hazard to first responders and rescue team.

**Keywords:** sustainable; green design; fire safety; PV fire; ecology



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## 1. Introduction

Energy, green buildings and fire safety seem at first to be unrelated, but in fact they are closely related. One of the goals of green buildings is energy saving (e.g., insulation materials) and sustainable energy (e.g., solar power generation), which leads to doubt regarding the fire load and possible ignition sources. According to the International Energy Agency (IEA), worldwide energy demand is expected to rise at a rate of 4.6% in 2021, more than the 4% reduction in 2020 during the COVID-19 pandemic, and pushing demand 0.5% above 2019 levels [1]. Prior to the crisis, energy demand was set to increase by 2.1 % per year to 2040 and was projected to grow by 12% between 2019 and 2030 [2], which is consistent with the growth of population and rapid development of industry. Therefore, energy demand is increasing day by day. Traditional fossil fuels can supply this energy demand, but the cost is serious environmental pollution and climate change. The purpose of actively promoting green and sustainable construction worldwide is to protect the environment. For example, natural ventilation and daylight are used to reduce energy consumption and better waste management and water conservation are taken into consideration. The green single-family housing market increased from 2% in 2005 to 26–33% in 2016 [3] and it has become one of the fastest growing industries worldwide [4]. In the USA, residential buildings accounted for about 22% and commercial sectors accounted for 18% of total U.S. energy consumption which is respectively 40% combined in 2020 [5]. It is the same value during the past ten years for residential and commercial buildings account for approximately 40% of the total primary energy consumed as well as 40 % of the total carbon dioxide (CO<sub>2</sub>) emissions [6]. According to the open letter to the European Commission in 2017, “without a better understanding of fire safety technologies needed to protect our citizens, we cannot provide a safer life to our citizens and to those who live among us or just visit Europe” [7]. It also pointed out the same problem of energy, green buildings, and fire safety. More than 98% of Taiwan's energy supply depends on imports, and it is highly dependent on petrochemical energy. No one can opt out of the global shifts

in behaviour needed to address climate change. Therefore, Taiwan's energy transformation plans to reduce coal, increase natural gas, develop green energy, and non-nuclear clean energy as its development direction. The goal of the plan is that by 2025 renewable energy will account for 20% of the total power generation.

## 2. Problem Discussion

Green buildings have energy and environmental benefits such as thermal insulation and water saving. However, they also raise questions about the side effects of fire safety. Therefore, there are two main problems for the connection between fire safety and sustainable design. The first is the environment and how building fires will harm the environment. The second question is whether sustainable design features will lead to unexpected fire hazards or increased fire risk.

### 2.1. Fire Casualties and Losses

Fire casualties and losses are a reference for evaluating fire protection and construction policies. In recent years, the growth trend of fire has focused on the field of building fires. In 2008, an estimation of global fire deaths was 180,000 annually and the vast majority of these in low and middle-income countries, with fewer fire safety regulations or provisions by the World Health Organization (WHO) [8]. After ten years, the WHO presented the same fire casualty figures and mainly concentrated on the same area [9]. The situation of fire casualties from 2008 to 2018 was still severe and more efforts are needed to improve the plight today.

Fire casualties in developed countries such as Europe and the United States are similar and equally serious. There were 1,291,500 fires in the United States in 2019, which caused an estimated 3704 civilian deaths, 16,600 civilian injuries, and 14.8 billion USD in direct property damage [10]. There were more than 3500 civilian deaths and 70,000 civilian injuries per year in fires according to a five-year average report in the EU, in 2018 [11].

The cost of fire is estimated to be more than 1% of gross domestic product (GDP) in most advanced countries. The analysis by Allianz of business interruption claims globally due to fires and explosions in building environment accounted for 59% [12]. According to this standard, the cost of fires in Taiwan is about 6.67 billion USD based on 1% of the average value of Taiwan's GDP over a five-year period (2016–2020) [13,14]. Therefore, business interruption claims of building fire and explosion incidents should be  $59\% * 1\% (\text{GDP}) = 3.9$  billion USD. It shows that the fire damage situation in both developed and low- and middle-income countries is disturbing.

### 2.2. Are Greening Technology against Fire Safety?

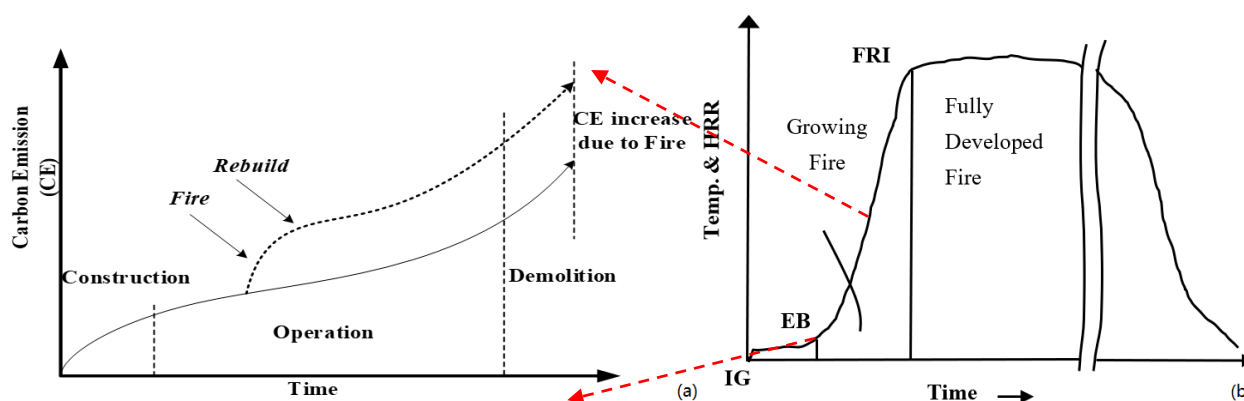
The aforementioned questions about green buildings and fire safety cannot help but make people think—will there be better or worse fire safety in green buildings? Although there is no direct report of fire accidents in green buildings or structures with green elements, the indirect conditions can still be used to illustrate the potential hazards of green buildings and fires. Taking the characteristics of residents as an example, education and health care facilities are the main sectors accounting for about 40% in green building market [15,16]. There are vulnerable groups with relatively limited mobility in education and health care facilities, which directly affects the life safety of green building fires.

## 3. Fire and the Greenhouse Effect

The greenhouse effect is a global warming issue. In connection with green buildings, most people only think of projects with environmentally friendly materials. However, research shows that structural fires caused a lot of CO<sub>2</sub> emissions, which has worsened the greenhouse effect. The residential fires in USA between 1999 and 2008 released almost 1 million metric tons of CO<sub>2</sub> equivalents (CO<sub>2</sub>e) [17]. That is about 100,000 tons of CO<sub>2</sub> emitted every year by residential fires, which is approximately equal to the greenhouse gas

(GHG) emissions of 400,000 recreational vehicles (RVs) with internal combustion engines (ICE) driving 1000 km.

Residential fires and subsequent reconstruction will increase the carbon dioxide emissions of the building's entire life cycle by 2% to 14%, and the carbon dioxide emissions during the fire and reconstruction process will also increase, especially as the burning time increases. Once the fire burns independently and enters the growth stage, the heat release rate (HRR) will be proportional to the CO<sub>2</sub> emissions. It is consistent with the fire growth curve of HRR, as shown in Figure 1 [18,19].



**Figure 1.** (a) Fire impacts a building's life cycle carbon emissions [18] integrated with (b) Fire growth curve [19]. Ignition (IG), Established Burning (EB), Full Room Involvement (FRI). (Adapted with permission from ref. [18]. 2021, FM Global. And Adapted with permission from ref. [19]. 2021, The Society of Fire Protection Engineers (SFPE)).

### 3.1. Green Building Materials and Fire Performance

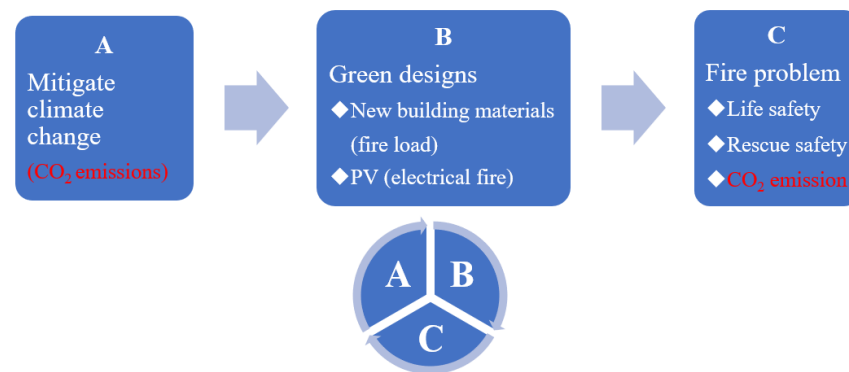
Sustainable construction is one of the fastest growing industries in the world, and so sustainable design is a relatively new market. The materials and design changes are taking place to achieve the goal of sustainable design for the purpose of energy saving and environmental benefits. It contains some unconventional materials and functions that haven't been proven by time, which may bring risks of unexpected results, such as green building materials or fire load. In order to meet the need for sustainability and/or energy efficiency, new structural designs and materials are quickly developed without comprehensive understanding of their fire performance.

It will be very valuable to combine green design with fire safety so that they can promote each other rather than destroy each other. For example, the aforementioned fire extinguishing system consumes a large amount of water resources that can be incorporated into green design and fire safety by combining grey water and rainwater reuse systems with a fire sprinkler system. This is consistent with the design of the waterway-connected sprinkler system promoted by the Taipei Hospital Nursing Home Fire in 2018. It has an economical, safe, and green design, which is a practical and feasible way to implement it.

### 3.2. Climate Change Increased Fire Risks?

The Sustainable Development Goals (SDGs) were adopted by the United Nations in 2016 as part of The 2030 Agenda for Sustainable Development (A/Res/70/1) [20]. Furthermore, one of the key messages of the 5th Assessment Report from the Intergovernmental Panel on Climate Change (IPCC) is that we have the means to limit climate change and build a more prosperous, sustainable future [21]. How will climate change increase fire risks? Both the SDG and IPCC reports focus on sustainable development that is consistent with the concept of sustainable design. In addition, the reports look into the study of wildfires, which is already a common fire problem faced by the world. The other topic is the aforementioned fire safety issues arising from the development of green buildings to save energy and reduce carbon emissions in response to climate change. Energy-saving sustainable buildings and green energy have been adopted to mitigate climate change. The

most common ones among these green designs are new building materials but cause fire safety doubts, and photovoltaic (PV) system but causes electrical fire problems. These all could lead to serious fire problem. As a result, the issues concerning the life safety and rescue operations in fires have arisen. The description is simplified in Figure 2. It can be a vicious circle or a virtuous circle depending on if the building is designed properly or not.



**Figure 2.** Relationship between climate change, green design and fire safety.

Nowadays, fire safety research only focuses on the principle of heat transfer and fire dynamics. The principles of heat transfer and fire dynamics, which occupy an important academic position in fire protection research, have been transformed into traditional fire science over time.

In addition, the cost of traditional fire safety only focuses on the cost of fire service, casualties and property damage, and lacks sufficient data on indirect losses. The same is true in advanced countries, so it is difficult to quantify the actual economic cost of fire. Although there is a lack of data to determine the status and economic impact of fire safety, the economic and environmental costs of fires can be accounted from the business interruption claims of structure fires and the carbon emissions during building fires and reconstruction. Therefore, if fire science can combine the environmental factors of fire, greenhouse gases and climate change, it can contribute greater benefits.

### 3.3. Can Sustainable Construction Be Combined with Fire Safety: Take Sprinkler and Fire Alert as an Example

General building fires are classified as Class A fires [22], and the most suitable extinguishing agent is water. This is due to the convenience of easy access to water and the heat of vaporization of water being 2266 kJ/kg·K which can quickly take away the fire energy (cooling down the fire) if it can be used effectively. Fire-fighters use water-stream and pumps to put out the fire with straight stream. It has a good extinguishing function for growing fires or fires above a certain scale, but it also causes water damage to the structure at the same time. Most of the straight stream will flow to the ground causing flood damage to other rooms on the same floor and low-rise buildings that are not affected by the fire. Another design for decentralized use of water systems to extinguish Class A fires is the sprinkler system. It can effectively extinguish the initial fire with a small amount of water and greatly reduce water damage. The National Fire Sprinkler Association (NFSA) has always advocated the use of fire sprinkler systems as a standard for green certified buildings and that will greatly reduce the impact of fire on the environment. Combining gray water and rainwater reuse systems with fire sprinklers to save water resources can be incorporated into green design, because fire extinguishing consumes a lot of water. The benefits of decreased water damage to buildings, decreased water consumption and GHG emissions in fires can all be achieved through sprinkler systems [23].

After the experience of the serious fire in the nursing home of the Taipei Hospital where 15 people died and 37 people injured in an early morning of August 2018, the design of Taiwan's current promotion of waterway-linked sprinkler systems for nursing

homes are only based on safety and economic considerations. This kind of simple sprinkler system uses less water, and water pressure is supposed to limit the fire growth instead of extinguishing it. Furthermore, it does not require generators and main pumps as is the case with ordinary sprinkler systems. If we further consider the green design of effective fire extinguishing water sources and reclaimed water recycling, it will be a good example of the combination of sustainability and safety. Studies have shown that a typical fire extinguishment requires approximately  $138 \text{ dm}^3/\text{m}^2$ , and a general building fire requires  $13,338 \text{ dm}^3$  of fire-fighting water-stream while the sprinkler only needs  $1060 \text{ dm}^3$  to suppress the initial fire [24]. It effectively reduces the HRR peak to below  $300 \text{ kW}$  which avoids the flashover conditions of  $600 \text{ }^\circ\text{C}$  and  $20 \text{ kW}/\text{m}^2$  of heat flux in the compartment. At the same time, the pH of the wastewater produced by the fire-fighting operation is also significantly decreased to reduce the ecological damage of the environment.

In addition to the active protection fire extinguishing system, the early warning system (fire alarm system) is another example which can also be integrated with building information models (BIM) and building automation systems (BAS). BAS is a network composed of computers, monitors and controls that can optimize the performance of systems including HVAC (heating, ventilation and air conditioning), security, fire, flood, alarm and lighting systems. The buildings controlled by BAS are called smart buildings or intelligent building.

In recent years, one of the most popular topics of architecture engineering construction (AEC) in the global construction engineering industry was the building information modeling (BIM) [25]. BIM has the advantages of improving accuracy, synchronizing design, improving energy efficiency, and promoting sustainable development in terms of commercial benefits and it is widely used in the AEC industry. For fire safety of building, the accuracy of BIM's digital data can provide a great help in fire simulation modeling, and solve the 3 dimensions (3D) model problem which is one of the biggest difficulties in fire simulation. The digital building model of the 3D drawing is constructed into a "virtual building", which can be transformed into the obstacle (OBST) object parameters of the fire dynamics simulation [26]. It applies 3D engineering information management to business management, while taking into account the management and business aspects, and can improve the penetration rate of the application. It is also in line with the goal of sustainable building and can be used as a reference material for a modeling database of fire simulation software in the future.

Alarms can be issued for abnormal phenomena (intrusion, temperature, smoke particles, water), and transmitted to relevant personnel (residents, managers, response agencies or fire department etc.) through the network for timely response processing, such as a smart cloud fire alarm system. Green buildings should not only energy-saving and environmentally friendly, they should also be able to evolve to use intelligent building safety management. For example, the design of the fire alarm system to stop the central air-conditioning system which is the safety design of Taiwan hospitals to prevent the spread of fire and smoke, and the integration of smart sensors to help locate personnel in the event of a fire. In summary, the fire safety design, BAS and BIM could be combined in the architectural design stage towards sustainability and safety.

#### *3.4. Summary: Green (Green Design) and Red (Fire Safety) Interference*

The combination of green design and fire safety is a feasible and valuable method. It can start from the principle of heat transfer, fire dynamics and fire safety to combine with ecology, economics and environmental costs. Through the on-site investigation of the green building fire case, not only the cause of the fire, but also the path of combustible burning and the design of green building materials are further investigated. In particular, small fires with shorter burning time and minor burn patterns can leave clear evidence of the continuation of burning worthy of reference compared with large-scale fires.

Cross-field cooperation in green design, fire safety and other scientific disciplines, is fundamental and important, especially the accurate and reliable information that has



been effectively investigated. The Fire Information Exchange Platform (FIEP) is a practice worthy of reference [27]. It can also provide directions for fire investigation and green building research.

Therefore, research in the field of fire science and engineering can help solve recognized social needs and social challenges such as green building fire safety.

#### 4. Changes in Fire Hazards Factors

The World Green Building Council defines a green building as one that “in its design, construction or operation, reduces or eliminates negative impacts, and can create positive impacts on our climate and natural environment” [28]. The steps for green buildings to achieve sustainable development include reducing materials, energy, and developing better waste management, reducing energy consumption through natural ventilation, and using recycled resources, as well as saving water. The methods include effective use of energy, water, renewable energy, recycling and increasing the use of materials, thermal insulation and passive ventilation.

##### 4.1. Classification of Fire Hazard Factors

Generally, fire hazard factors related to fire safety research are mostly classified according to the structure usage, ventilation (stack effect), management of ignition source and fire load, building familiarity and evacuees' ability. These traditional fire hazard factors are mainly analyzed from the characteristics of fire prevention management and occupants without considering social, environmental and economic factors.

Among them, the ventilation feature is an increase in passive ventilation related to the design of green buildings. According to the experience of fire protection experts and fire investigators, the growth of the fire is directly affected by the ventilation. Especially when the fire enters the growth stage to the fully development stage, the ventilation and the buoyancy of the fire airflow form a stack effect, which becomes the main cause of thermal convection to expand and burn, and causes the fire to burn vertically. The risk factor of ventilation (stack effect) coincides with the highest fire risk scores of the green building double skin façades (DSF) [29].

Further research has shown that porous materials with flame-resistant properties are fire retardant to slow down the ignition of these materials but not non-combustible. After adding a combustion accelerator such as gasoline and ignition, it can burn rapidly with a flame and become more dangerous than those without flame-proof treatment [30]. It exactly meets the requirements of the fire characteristics investigation of the thermal insulation materials. The porous nature of the insulation material itself is that the porous material structure contains air to reduce heat conduction compared to the traditional solid material structure, and it can increase natural ventilation or passive ventilation, so it is a common material for green buildings. Green technology differs from traditional buildings in terms of energy conservation is heat conduction. Typical thermal insulation materials follow the principle of air insulation and adopt a porous, flame-resistant green design. It had been initially incorporated green technology and fire retardant. However, from the point of view of fire safety, it is necessary to consider the combustion of the porous material when the combustible accelerating agent is adsorbed causes the flame resistance to fail and could therefore become a more severe combustion hazard.

The non-traditional fire hazard factors of sustainable green buildings are different and cover a wider range. The following items are discussed from a different perspective, which are different from the aforementioned traditional fire factors. They are listed below:

1. Population growth, aging and obesity: Inability to evacuate in time in the event of a fire increases the risk of fire.
2. The wealth gap: An increase in the gap between the rich and the poor will also increase the fire safety gap. It is the foundation of fertile ground for international instability and unequal development.

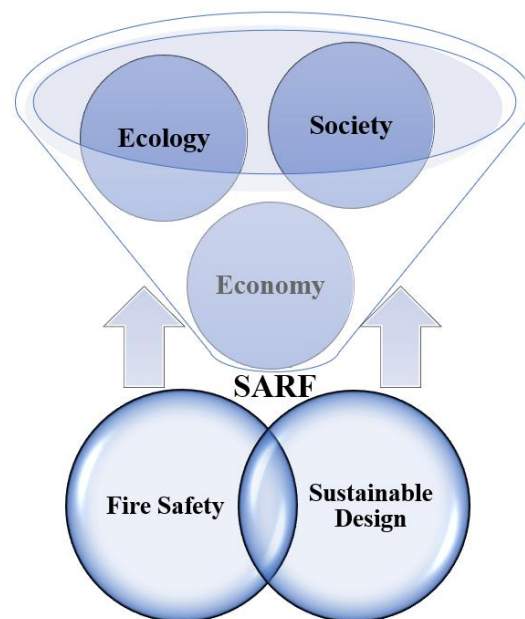
3. Cyber attacks: Cyber attacks on critical security systems can be used to cause fires and explosions.
4. Climate change: It is directly related to the risk of global wildfires and has a significant impact on the wildland-urban interface (WUI).
5. Urbanization: The rapid population growth and concentration, and the increase in building density have led to an increase in the number of fires and casualties.

The most recent incident of the above-mentioned was the hacking of the oil pipeline incident on 10 May 2021 which caused the interruption of the “Colonial Pipeline” which supplies 45% of the oil pipeline on the east coast of the United States, and caused the potential fire risk of an emergency state of fuel accident.

#### 4.2. Resilience

The National Research Council define disaster resilience as “the ability to prepare and plan for, absorb, recover from, and more successfully adapt to adverse events” [31]. Regardless of the traditional and non-traditional fire hazard factors, they are protecting the life safety, reducing casualties and property losses. It is the ability to recover after a disaster. It is consistent with the urban resilience concept of sustainable architecture for the resilience of historical buildings: long-term preservation and transmission of human wisdom and culture.

Therefore, the intersection of fire resilience and sustainable building is a new concept, which can be simplified as Sustainable And Fire Resilient (SAFR) Buildings Concept [32,33], and merged with the aforementioned social, ecological, and economic fields [27], as shown in the Figure 3.



**Figure 3.** The concept of sustainability & SAFR.

The 100 Resilient Cities program defines urban resilience as “the capacity of individuals, communities, institutions, businesses, and systems within a city to survive, adapt, and grow no matter what kinds of chronic stresses and acute shocks they experience” [34]. It is distinguished by the resilience of individuals, groups and the overall system. The principle of self-help, mutual assistance, and public assistance is the same with the resilience of historical buildings. The ratio is 7:2:1.

#### 4.3. The Trend of Combining Architecture, Fire Protection and Other Disciplines

In terms of market and economy, the scale of the architecture construction industry is larger than that of the fire protection industry. However, in terms of life safety, the two are equally important. The trend of sustainable construction is to accommodate more people within a small area due to population growth and urbanization, requiring the development of new materials and architectural design. At the same time, it faces fire safety issues.

The key items of fire safety and sustainability include fireproof materials with low environmental impact and safe energy storage/energy-saving materials, etc. In addition to sustainable construction and fire engineering, there are also fields such as climate change, population structure and globalization of science and technology that are closely related. Green design and fire safety research cannot live on its own island. It needs to form cross-domain alliances with other disciplines and society to exchange information and related fire cases. The aforementioned FIEP is an excellent example.

#### 4.4. Thermal Insulation Is not Equal Flame Resistance

Sustainable buildings focus on energy saving and carbon reduction, and the methods include reducing the life cycle energy and environmental costs of the site. Therefore, combining recycled materials (plastics, newspapers, wood chips and textile waste) with building materials including wood, concrete and steel is one of the green building design methods [35]. Whether the sustainable characteristics of one or more elements of these green designs will cause fire risks has indeed attracted the attention of the fire safety group. Thermal insulation is one of the most concerned areas, and a common example of energy saving in green building structures is insulation materials. In particular, foam insulation materials are worrying for fire safety experts. There is a core concept that heat insulation does not equal flame resistance.

From the heat conduction equation of fire dynamics engineering, the thermal inertia ( $k\rho c_p$ , where  $k$ : thermal conductivity;  $\rho$ : density;  $c_p$ : heat capacity) is the value that determines the energy penetration [36]. The material with the smaller thermal inertia ( $k\rho c_p$ ) is a good material for heat insulation. For example, PU foam:  $9.5 \times 10^2$  ( $\text{W}^2 \cdot \text{s}/\text{m}^4 \text{K}^2$ ), compared to concrete:  $2 \times 10^6$  ( $\text{W}^2 \cdot \text{s}/\text{m}^4 \text{K}^2$ ), the difference in thermal inertia is about  $2 \times 10^3$  times. It can clearly understand that foam plastic can have a good heat insulation effect, but it is not a flame-resistant material (or even an extremely flammable material). The relevant case is as follows. In 1992, a vegetable processing building in Yuma, Arizona adopted appropriate fire-stop technology and insulated it with plastic foam. The air entrainment forming a ventilation which helps combustion and fire expansion. Although there are fire barriers, due to the sufficient air between the insulation layers, the fire spreads unimpeded throughout the hidden space [37]. Therefore, thermal insulation is not equal to flame resistance nor is it non-combustible.

### 5. The Hazards of Photovoltaic (PV) System and Firefighting Tactics

One of the sustainability goals of green buildings is renewable energy and green energy, such as solar power generation. Taiwan's photovoltaic development plan is expected to reach the 500 MW in 2025, which is equivalent to 2.5% of the government's promotion target of 20 GW. The PV systems are mainly installed on unobstructed roofs to obtain long-term sunlight.

#### 5.1. PV Fire Characteristics

Photovoltaics are installed in high places and the fire has the characteristic of upward burning. This kind of photovoltaic fire does not commonly cause downward burning danger for lower floors. That is to say, it is not easy for the entire building to burn completely due to the PV fire on the roof. However, it has multiple hazards to firefighting operations. Firefighters have to pay attention to the danger of falling from a high place, narrow space operation, and the risk of electric shock at the same time.



The main hazards of PV fire are the risk of electric shocks from solar power generation and the risk of slipping and falling off inclined roof panels. For buildings equipped with PV systems, there is a risk of continuous power supply (AC 220 V to 600 V and DC up to 1000 V) in the power storage equipment and part of the wiring [38]. DC arc faults are more dangerous than AC arcs in PV system. The continuous power supply is possible only for the DC side of the PV system even if the power is cut off automatically in the fire.

### 5.2. Hazards of PV Fire

PV fire has the characteristics of electrical fire and chemical fire at the same time. This study summarizes the PV fire hazards as follows:

- (1) The ignition causes of internal PV system with a risk of electric shock by DC arc fault and overheating or local overheating [39].
  - I. Error or poor mechanical installations.
  - II. Low quality of PV components.
  - III. Degradation of PV components which leads to spontaneous ignition.
  - IV. Hot spot effects.
  - V. Defective or damage system components or product failure.

- (2) Sloping roof panels are dangerous to slip and fall that constitute an obstacle to rescue. Firefighters' vision and mobility are limited due to full gear load and SCBA. It is very difficult for firefighters to deal with the sloping roof covered in smooth solar panels.

- (3) Incomplete power off

It is a standard operating procedure (SOP) for fire-fighting operations to cut off the utility power in a structural fire to avoid the electric shock caused by the fire-fighting stream. However, the SOP for buildings with photovoltaic systems on fire is different. Even if the utility power cut off completely, the power from PV can still generate potentially lethal power.

It should be noted that even if the fire occurs at night, the solar PV module is affected by the flame illuminance of the fire field which may cause the PV system to generate electricity. Therefore, no matter when a fire occurs during the day or night, the PV modules may be able to generate power [40].

- (4) Toxic material exposure

The battery stack for storing electric energy may contain a large amount of concentrated energy, which may cause a variety of hazards in a fire. Especially when the PV system fire extended to the storage equipment, the internal chemicals burn to produce a lot of dense smoke seriously affects visibility. The lead-acid battery contains highly corrosive and toxic sulfuric acid constitutes a practical obstacle to firefighters, and even causes injuries and deaths. Even though most of PV systems are on-grid with no batteries. However, toxic hazard remains mostly due to toxic additives to the PV cells.

- (5) Narrow operation spaces

In order to generate more electricity efficiently, most of the roof area is installed with PV systems leaving only narrow passage space. Therefore, the number of PV panels not only means that the PV distribution range is wide and the combustible material (fire load) will increase, but it may also mean that there is not enough working space on the roof. It means that in the event of a fire, the fire-fighting operation space is narrow, and the rescue route and escape route may be restricted, being a physical obstacle for firefighters.

### 5.3. Firefighting Tactics

The fire-fighting tactics of PV fire can be planned based on the fire characteristics and risk factors analyzed above. The supplementary rescue principles are summarized as follows [41]:

- (1) Use dry powder or gas fire extinguishing agent as much as possible.

- (2) Dry and full gear with SCBA.
- (3) Use the fog stream with an expansion angle of 30 degrees or more at a distance of 6 to 10 m or more, and the nozzle pressure should be at least 7 kgf/cm<sup>2</sup> (100 psi) in necessary. Do not rush out of solid stream unless with sufficient safe distance.
- (4) Do not touch or destroy PV system unless necessary.

## 6. Conclusions

This article discusses the inclusiveness of sustainable construction and fire safety, and emphasizes that communication between specialists in these two fields is beneficial. It can improve the exchange between the two fields and integrate with other disciplines, as well as with society, across domains. There is no need to sacrifice fire safety in the name of sustainability. In this paper, we came to the following conclusion:

- (1) There is no direct report of fire incidents with green design elements. However, indirectly from the characteristics of residents, green buildings have a high degree of intersection with vulnerable groups, which directly affects the life safety of green building fires.
- (2) The onsite water systems collect non-potable water and treat it in sustainable building (green building). This combined with a simple waterway-connected sprinkler system can reduce environmental impact (GHGs and alkaline wasted water in fire), save water resources, effectively extinguish fires and reduce fire stream damage. It will be an excellent example of cooperation between green (Green Design) and red (Fire Safety).
- (3) The non-traditional fire hazard factors of sustainable green buildings are different and cover a wider range. The following items are discussed from a different perspective, which are different from the aforementioned traditional fire factors. The intersection of fire resilience and sustainable building is a new concept which can be simplified as SAFR Buildings Concept, and merged with the aforementioned social, ecological and economic fields, as shown in the Figure 3.
- (4) There is a risk of continuous power supply (AC220 V to 600 V and DC up to 1000 V) in PV systems even if the power is cut off automatically in the fire. Whether there is a photovoltaic fire during the day or night, the PV modules will generate lethal electricity, which is a potential hazard to first responders and rescue teams.

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