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REIMAGINING FACILITY MANAGEMENT: A CRITICAL SHIFT TOWARDS PROACTIVE OM&R SAFETY

Nicholas Tymvios[a,*], Jake Smithwick[b]

[a] *Civil and Environmental Engineering, Bucknell University Dent Drive, Lewisburg, PA 17837, USA*
[b] *Faculty of Engineering Technology & Construction Management, University of North Carolina - Charlotte, 9201 University City Blvd, Charlotte, USA*

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Abstract

Safety during Operations, Maintenance, and Repair (OM&R) activities in buildings is a critical concern, often resulting in preventable incidents. This research addresses the gap in proactive safety measures by advocating for increased involvement of building facility management professionals early in a building's lifecycle. To qualitatively and quantitatively assess safety incidents, OSHA investigation summaries from 2014 to 2023 were analyzed, focusing on key building elements and equipment including skylights, solar panels, and HVAC in the United States. The analysis examined worker activities, work settings, injury types and severity, building phase, and the nature of the work performed. The primary goal is to develop recommendations that emphasize facility managers' role in the design phase, ensuring that safety considerations for OM&R personnel are integrated from the outset. By redistributing risk and responsibility, this study aims to foster safer working environments and prevent future safety incidents, promoting a proactive approach to building safety.

Keywords: safety; design for maintenance; facility management; building safety; OM&R.

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1. Introduction

The safety landscape of the modern built environment is largely dictated by decisions made during the brief window of a facility's conception. While the design and construction phases are relatively short, building owners plan for a structure's lifecycle to last several decades. In any case, a structure will have a relatively short construction period and a much lengthier occupancy timeframe [1–3]. Historically, safety interventions have been reactive, occurring only after occupancy reveals inadequacies in the original design [4]. This research advocates for a shift toward Prevention through Design (PtD), specifically focusing on the integration of Facilities Management (FM) expertise during the pre-occupancy stages to mitigate recurring hazards in Operations, Maintenance, and Repair (OM&R) [5, 6]. This paper aims to bring to attention that our infrastructure (buildings included) is aging and requires increasing investment and time in maintenance and repair activities [7]. In conjunction with the booming installation of new building systems in existing structures, such as photovoltaics, safety incidents are bound to become more prevalent [8]. This study distinguishes itself from prior research by providing an analysis of maintenance and repair incidents, bridging a critical gap by advocating for the integration of Facility Management (FM) insights, a domain that has remained largely overshadowed by traditional construction-site safety data.

2. Literature review

2.1. The temporal mismatch in risk distribution

A recurring tension in facility safety is the disconnect between those who design the space and those who must maintain its systems. Decisions made during design to optimize aesthetics or initial

*Corresponding author. *E-mail address:* nicholas.tymvios@bucknell.edu (Tymvios, N.)

construction costs often create "legacy hazards" that OM&R personnel must navigate for decades [9]. When safety concerns arise post-occupancy, such as the need for specialized equipment access or fall protection, facility managers are forced to implement retroactive modifications [10].

These modifications typically fall into the lower tiers of the Hierarchy of Controls, such as administrative changes or personal protective equipment (PPE), which are inherently less effective than the high-level elimination, substitution, or engineering controls possible during the design phase [11–13]. The ability to influence safety performance is at its peak during the earliest stages of a project; as the project moves toward occupancy, the cost of change increases while the opportunity for hazard elimination plummets [9].

2.2. Spatial complexity and systemic hazards: HVAC, solar, and integrated elements

The safety of OM&R personnel is often compromised by the spatial configuration of building systems. While the rooftop is a high-visibility hazard zone, many critical incidents occur within the facility's interior or at ground level, where the "as-built" environment conflicts with the physical requirements of maintenance tasks [14–17].

a. The ubiquity and accessibility of HVAC systems

Heating, Ventilation, and Air Conditioning (HVAC) equipment represents one of the most frequent touchpoints for OM&R personnel, yet its placement is often dictated by floor-area-ratio (FAR) optimizations rather than serviceability. Incidents involving HVAC systems are not confined to rooftops; they span a variety of high-risk environments:

- Indoor mechanical rooms: These often become "cramped environments" where technicians must navigate high-voltage electrical panels, pressurized vessels, and rotating machinery in confined spaces not originally designed for human ergonomics [18, 19].

- Ceiling plenums and vertical shafts: Maintenance of Variable Air Volume (VAV) boxes or ductwork often requires working from ladders or scaffolding in high-traffic areas, introducing fall hazards and overhead work risks that are rarely mitigated by permanent engineering controls [20].

- Ground-level chillers and cooling towers: Proximity to vehicular traffic or unprotected electrical components at ground level introduces a different set of environmental hazards [21].

When HVAC units are placed without regard for "safe access zones," technicians are often forced to adopt awkward postures or utilize improvised platforms, significantly increasing the probability of a musculoskeletal injury or a fall [19, 21].

b. Renewable Integration and Electrical Complexity

The rapid adoption of Solar Photovoltaic (PV) systems has introduced a new layer of complexity to the facility safety map [22]. Beyond the rooftop, solar integration involves a network of inverters, conduit, and battery storage systems that intersect with traditional building utilities. While photovoltaics can be turned off during daylight hours through rapid shutdown technology, the energized nature of the integrated system remains a primary concern. This creates a high-voltage hazard for FM personnel working on adjacent systems – such as repairing a roof leak or servicing a nearby HVAC unit – who may be exposed to live PV strings if de-energization protocols are not properly coordinated or if the system's status is not clearly communicated. Specific risks associated with PV maintenance include shocks, arc flashes, solar heating, and fires [23].

c. Openings and walking-working surfaces

While skylights are the most prominent "fall-through" hazard on rooftops, the danger of "existing openings" extends throughout the building lifecycle. OSHA identifies these as "holes" (29 CFR 1910.28) [24], which includes floor openings, hatchways, and pits found in mechanical rooms and industrial settings. The hazard is rarely the building element itself, but rather its proximity and interaction with other systems [25]. For instance, a technician focused on an HVAC control panel may be unaware of a nearby floor hatch or a fragile skylight if the design does not provide a physical barrier or a clear "buffer zone." By analyzing OSHA summaries across these diverse settings, this research identifies how the spatial relationship between equipment (like HVAC) and hazards (like openings or solar arrays) dictates the frequency and severity of incidents.

2.3. Data granularity challenge in OM&R safety

A significant barrier to improving OM&R safety is the "classification gap" within national incident reporting. Current datasets, such as those provided by the Bureau of Labor Statistics (BLS), often mask the true nature of OM&R hazards by categorizing incidents based on the employer's North American Industry Classification System (NAICS) code rather than the specific activity being performed [12, 26, 27].

For example, a fatality involving a technician repairing a rooftop HVAC unit might be coded under "Manufacturing" if the technician is an in-house employee of a manufacturing plant (NAICS code 31-33), or "Construction" if they are a third-party construction contractor (NAICS code 23). In other words, workers performing exactly the same work, and getting injured while performing their tasks, will be categorized according to their employer's NAICS number. This lack of granular data makes it difficult for designers and owners to quantify the specific risks associated with building elements like solar panels or skylights. By analyzing OSHA investigation summaries from 2014 to 2023, this study seeks to bypass these classification hurdles, providing a qualitative and quantitative assessment of the direct relationship between building elements and worker safety incidents.

2.4. Proactive integration of facility management

To redistribute risk and responsibility effectively, the role of the Facility Manager must be elevated from a post-construction "caretaker" to a pre-construction "consultant." Facility managers possess the "operational intelligence" necessary to identify how a specific HVAC placement might interfere with safe skylight maintenance or how solar panel orientation might create tripping hazards [28]. Integrating FM professionals into the design phase ensures that the personnel who will eventually bear the risk of the building's layout have a voice in its creation, fostering a proactive rather than reactive safety culture.

3. Methodology

The primary objective of this research was to identify worker demographics during recurring safety incidents across specific building elements (skylights, solar panels, and HVAC). A mixed-methods approach was employed, combining qualitative content analysis of OSHA investigation narratives with quantitative descriptive statistics to identify these trends, and to associate these incidents to OM&R activities. The researchers chose these building elements for a variety of reasons. Skylights were selected since skylight investigation was part of a previous research project [29], and the authors expanded that investigation's timeline from 6 to 10 years. Solar panels were chosen since they are also another roof building element that can be readily identified from satellite images, and their addition on existing structures, can be tracked using historical satellite images. HVAC systems were chosen to expand the research project to more dynamic building elements, and the total number of incidents during the ten-year timeframe was manageable for this project. The authors also considered the inclusion of other building elements such as windows and doors, ladders, and catwalks, but due to the volume of incidents associated with these elements, the authors made the decision to include them in future investigations.

3.1. Data source and case selection

Data for this study were retrieved from the Occupational Safety and Health Administration (OSHA), Fatality and Catastrophe Investigation Search database [30]. The search was bounded by a ten-year period from January 1, 2014, to December 31, 2023. One of the authors collected the information from all the OSHA incident reports, and tabulated the results, while the other author validated the responses for a subset of the cases. Inter-rater reliability was not performed; however, the research team verified each other's classification to ensure coding consistency.

To ensure the relevance of the cases to OM&R and the specific building elements of interest, a keyword-based filtering strategy was implemented. The search terms included:

- Skylight related: "Skylight".
- Solar Panel related: "Solar", "Photovoltaic".
- HVAC related: "HVAC", "Air handler", "Air conditioner", "Exhaust fan", "Condensing unit", "Cooling tower", "Chiller", "Energy recovery", "Heat pump", and "Duct".

It is possible that some cases might not have been included with this methodology, since the search required that OSHA personnel correctly include keywords and description of the incident in the abstract. So, for example, if an incident involved a fall through a skylight, and the description and abstract did not mention the skylight, the incident would not appear in this search. The authors recognize this as a limitation, but with the number data that was collected, meaningful conclusions can still be extracted from this investigation.

Initial results were manually screened, by reading the abstract of each incident, to exclude incidents not relating to the building element of interest. By examining the summary number for each incident, any duplicate entries were removed. As identified in Table 1, there were 365 unique incidents involving skylights with 367 victims, 91 incidents involving solar panels with 92 victims, and 454 incidents involving 465 victims.

Table 1. Identified unique incidents and victims for each building element of interest

Category of incidents	Number of unique incidents	Number of victims
Skylights	365	367
Solar panels	91	92
HVAC	454	465

3.2. Data extraction and coding framework

Each incident was treated as a unique case study. To systematically categorize the qualitative narratives alongside the details from each summary, a coding framework was developed and categorized based on the following descriptors:

- Worker activity at the time of the incident.
- Employer NAICS category.
- Structure type, and function.
- Injury severity.
- Address where the incident occurred.
- Victim demographics.

a. Worker activity designation

Worker activity at the time of each incident was categorized according to the following: new construction, addition, repair or replacement, maintenance, operations, and demolition. These categories, shown below, were determined by the abstract within each incident report, and by Google Maps historical images, that show each structure over time [31]. The use of Google Maps has been previously used in research projects to collect a variety of information [32, 33], and it has been proven to be accurate.

- New construction was indicated when there was a specific statement in the report, or when during a historical image from Google Earth at the site location depicted a structure under construction, or a structure appeared on the site between two successive historical images on Google Earth.

- Addition was also indicated by the narrative and similarly to "new construction" when a portion of the building was added to an existing structure, or a new system was added to the structure according to both the narrative and the images. Such an example would be the addition of solar panels on a site where an existing structure in one historical image does not have solar panels on the roof, and during a subsequent one there are. Also, the narrative would have descriptions such as "... installing new solar panels on an existing residential structure ...".

- Repair/Replacement would be designated by the narrative with descriptions such as "... was engaged in repair work on the roof ...", or "... worked on the replacement of an HVAC unit wires ...".

- Maintenance would be designated from the narrative with statements such as "... an employee was cleaning the coils ..." or "... they were preparing to pressure wash the roof ...", or "... prepared and set up equipment to clean solar panels..." or "... employee was looking for the cause of a roof leak ...".

- Operations was designated in situations where workers were performing other tasks related to the facility in question and had an incident with one of the building elements. Such examples included "... an employee was getting line of sight to a cell tower walking backwards ...", or "... next to a skylight on the roof of a paint shop to observe the installation of guy wires ...", or "... was walking on a roof to inspect for rat entry points ...", or "... began wiping feathers from his clothing ... as he was doing this; the fan started and its blades contacted his right forefinger ...".

- Demolition was designated by the OSHA incident summary, the abstract of each summary, and by observing the historical images around the date of the incident, and observing structures that had significant changes that required demolition of a portion (or complete structure) and its replacement with another.

- When none of the above designations were possible to be assigned, the designation of Not Available (NA) was given to the incident.

b. NAICS designation

NAICS stands for The North American Industry Classification System, it is a classification system that standardizes industry classification across the U.S., Canada, and Mexico. Each code categorizes a business establishment hierarchically according to their primary activities [34]. The OSHA incident summaries provide the NAICS number of each victim according to their employer. This categorization allows the identification of incidents according to the industry each victim belongs. For example, an NAICS classification of "238160" indicates the employer of that individual is categorized as a "Roofing Contractor", while an NAICS classification of "561210" indicates that an individual is employed by a "Facilities Support Services" firm. The first two numbers of the NAICS classification system provide the general industry that individuals belong to, with "23" being "Construction", while

"56" indicates the employer is in the broader area of "Admin Support and Waste Management and Remediation" [34].

By identifying the NAICS designation of individuals involved in safety incidents, we can distinguish between incidents where construction workers were involved that were doing construction work, or maintenance/repair work. By that token we can also distinguish where employees from other industries such as education, healthcare etc. are involved in incidents where workers were performing maintenance and repair work in their facilities.

c. Facility Type

Each investigation summary provides a classification of the facility at which each incident occurred. This classification will showcase where the incidents happen and which facility types require attention in order to address potential hazards early in the design phase. In cases where the structures type was not identified in the investigation summaries, the researchers relied on Google Earth and Google Maps [31] historical data. The classifications used in this manuscript were the following:

- Commercial – This categorization included facilities such as department stores, warehouses, hotels, industrial buildings, and manufacturing plants. A further categorization of these structures will be performed in a future publication.

- Multi-family dwelling – Apartments and condominiums.

- Single family/Duplex dwellings.

- Other – This category includes facilities schools, university facilities, stadiums, religious structures, etc.

4. Results

4.1. Nature of work and incidents

The distribution of incidents according to the nature of work is summarized in Table 2. As observed, with skylights and HVAC systems, a large proportion of safety incidents occur with work that relates to Repair/Replacement and maintenance operations. Specifically for skylights 153 (41.9%) of the incidents occurred during repair and replacement, and 138 (37.8%) during maintenance operations, adding up to 79.7% of the cases. For incidents involving HVAC equipment, these numbers are 221 (48.7%) for Repair/Replacement and 109 (24%) for maintenance with a total of 72.7% for both. By contrast the majority of the incidents involving solar panels occur during addition of new panels in existing buildings with 65 (71.4%) incidents, compared to the sum of maintenance and repair/replacement of 12 (13.2%). This disparity between solar panels and other systems might be due to the more recent exponential growth of installation of solar panels in U.S. buildings, where installation capacity increased eight-fold between 2014 and 2023 [35]. With the expected lifespan of solar panels being between 25-30 years [36, 37] the authors forecast that more incidents will be occurring during solar panel array maintenance (rewiring, cleaning) and eventual replacement.

By concentrating only on the skylight and HVAC incidents and further separating these incidents according to the NAICS classification of the employers, it can be observed that many of these incidents occur to workers who are employed in other industries than construction Table 3. Construction workers are involved in the majority of the incidents. Specifically of the 454 incidents that relate to HVAC systems, 275 incidents involved construction workers (60.4%). For the 365 incidents that relate to skylights, 256 involved construction workers (70.1%).

Table 2. Incident distribution according to nature of work and building elements

Worker activity	Skylights	Solar panels	HVAC
New construction	21 (5.8%)	12 (13.2%)	79 (17.4%)
Addition	4 (1.1%)	65 (71.4%)	15 (3.3%)
Repair/Replacement	153 (41.9%)	4 (4.4%)	221 (48.7%)
Maintenance	138 (37.8%)	8 (8.8%)	109 (24.0%)
Operations	24 (6.6%)	0 (0%)	15 (3.3%)
Demolition	13 (3.6%)	0 (0%)	4 (0.9%)
NA	12 (3.3%)	0 (0%)	11 (2.4%)

Table 3. Incident distribution between construction and all other industries

	Skylights		HVAC	
	Construction (NAICS 23)	All other industries	Construction (NAICS 23)	All other industries
New construction	20	1	72	7
Addition	4	0	15	0
Repair/Replacement	137	16	144	77
Maintenance	77	61	35	74
Operations	2	22	0	15
Demolition	10	3	4	0
NA	6	6	5	6
Total	256	109	275	179

4.2. Employer type and incidents

The prevalence of incidents during maintenance and repair is particularly concerning because a substantial portion involves workers outside the construction sector. As indicated in Table 4, non-construction employees are frequently exposed to OM&R hazards, a trend especially evident in HVAC operations. For skylight-related incidents, the majority of repair and replacement cases (89.5%) involved contractors, while the remaining 10.5% occurred among non-construction employers. However, for maintenance activities, the distribution shifts: 55.8% of incidents involved construction employers, while 44.2% occurred among non-construction employers, with manufacturing employees accounting for 15.9% of that total.

A similar pattern emerges in HVAC-related incidents. During repair and replacement tasks, 65.2% of incidents involved construction contractors, compared to 35% for non-construction employers. This disparity widens significantly during maintenance activities, where only 32.1% of incidents involved construction employers. The vast majority (67.9%) occurred among non-construction employers, specifically within manufacturing (18.3%), administrative support and waste management (11.9%), and accommodation/food services (9.2%).

These findings provide a critical insight: these hazards are not confined to the construction industry; they represent a pervasive facility management challenge. Because the majority of these incidents occur during the operational phase of a building's life, they are more accurately classified as OM&R incidents rather than construction accidents. This suggests that facility owners across diverse industries are overseeing high-risk tasks on systems that may not have been designed for safe serviceability. Furthermore, even when construction contractors are utilized, they are predominantly performing work on existing facilities, 81.25% for skylights and 64.85% for HVAC, rather than engaging in new construction.

Table 4. Distribution of repair/replacement incidents and maintenance incidents according to trade

Industry (NAICS Number)	Skylights		HVAC	
	Repair / Repl.	Maint.	Repair / Repl.	Maint.
Agr., forestry, fishing hunting (11)	0	3 (2.2%)	0	1 (0.9%)
Utilities (22)	0	0	2 (0.9%)	0
Construction (23)	137 (89.5%)	77 (55.8%)	144 (65.2%)	35 (32.1%)
Manufacturing (31-33)	4 (2.6%)	22 (15.9%)	21 (9.5%)	20 (18.3%)
Wholesale/Retail trade (42-45)	2 (1.3%)	7 (5.1%)	7 (3.2%)	3 (2.8%)
Transp. & warehousing (48-49)	1 (0.7%)	1 (0.7%)	4 (1.8%)	1 (0.9%)
Information (51)	0	5 (3.6%)	0	1 (0.9%)
Finance & insurance (52)	0	0	0	0
Real estate & leasing (53)	0	2 (1.4%)	3 (1.4%)	3 (2.8%)
Prof. scient. and tech. services (54)	0	1 (0.7%)	1 (0.5%)	1 (0.9%)
Mngmt comp. and enterprises (55)	0	0	0	0
Adm. sup. & waste mngmt and rem. (56)	6 (3.9%)	11 (8%)	6 (2.7%)	13 (11.9%)
Educational (61)	0	1 (0.7%)	8 (3.6%)	4 (3.7%)
Health care and social assist. (62)	1 (0.7%)	3 (2.2%)	7 (3.2%)	7 (6.4%)
Arts and entertainment (71)	1 (0.7%)	1 (0.7%)	1 (0.5%)	4 (3.7%)
Accom. and food services (72)	1 (0.7%)	0	3 (1.4%)	10 (9.2%)
Other services (81)	0	3 (2.2%)	8 (3.6%)	3 (2.8%)
Public administration (92)	0	1 (0.7%)	6 (2.7%)	3 (2.8%)
Total	153 (100%)	138 (100%)	221 (100%)	109 (100%)

The prevalence of OM&R incidents reinforces the need for FM integration during the design phase, and the need for the development of "operational intelligence" that is essential to identify how equipment placement, work locations, and paths of travel, in conjunction with proximity to hazards like skylights and HVAC equipment will impact worker and occupant safety for the next 30 to 50 years of a building's life.

4.3. *Injury severity*

Incidents involving skylights are characterized by extreme lethality. Out of 365 unique incidents analyzed, 185 resulted in fatalities, meaning more than half (50.7%) of reported skylight incidents are fatal (Table 5). This high fatality rate underscores the danger of skylights as prominent "fall-through" hazards when they lack permanent engineering controls like screens or railings.

While HVAC incidents resulted in 130 fatalities, they produced a much higher volume of hospitalized injuries (276) compared to skylights (Table 6), primarily to the fact that all of the skylight incidents resulted in falls from high elevations and the survival rate for these types of incidents is not high [29]. The average recorded fall height in the incidents used in this investigation was 23.1 ft (7.04 meters). The broader range of injury types in HVAC work likely reflects the spatial complexity and varied hazards of these systems, including mechanical contact in cramped indoor rooms, electrical hazards, and falls from ladders or in vertical shafts.

Table 5. Severity of injury and type of work for skylight incidents

	Fatality	Hosp. injury	Non-Hosp. injury	Total
New construction	12	8	1	21
Addition	0	4	0	4
Repair/Replacement	78	73	2	153
Maintenance	71	65	2	138
Operations	10	13	1	24
Demolition	7	6	0	13
NA	7	5	0	12
Total	185	174	6	365

Table 6. Severity of injury and type of work for HVAC incidents

	Fatality	Hosp. injury	Non-hosp. injury	Total
New construction	14	61	4	79
Addition	2	12	1	15
Repair/Replacement	71	126	24	221
Maintenance	34	60	15	109
Operations	4	8	3	15
Demolition	1	3	0	4
NA	4	6	1	11
Total	130	276	48	454

4.4. *Facility type*

The facilities that these incidents occurred were commercial in nature. After examining the incidents' locations and verifying the type of structure they occurred, the information was tabulated and is shown in Table 7. The researchers also identified the facility type with the nature of the employer and that information is also shown. As observed, for skylight and HVAC related incidents, the majority occurred at commercial facilities. That value was 296 out of the 365 (81.1%) for skylight related, and 249 out of 454 (54.8%) for HVAC related incidents. The second largest category for these incidents is the "Other" which includes structures that would be classified as schools, universities, religious buildings, and transportation facilities (Airports, etc.). These facilities, in general, along with the majority of the incidents that occurred in "Other" identified facilities, would employ facility managers to address day-to-day maintenance, and make decisions on long-term maintenance and repair [38, 39].

Incidents involving solar panels most often occurred at single family homes, which is unsurprising given the growth in U.S. incentives for residential installations [40, 41] and the increasing number of contractors offering solar installation as part of their services.

Regarding the NAICS classification of the workers involved in these incidents, as mentioned earlier, it is evident that the majority of the incidents occur with construction workers, but as observed, many of the incidents happen to other NAICS classifications, especially in "Commercial" and "Other" facilities, suggesting that the individuals injured are employed by the occupants of these facilities.

Table 7. Incident distribution by type of facility

Incident type	Worker type	Commercial	Multi-family	Single family	Other building	NA	Total
Skylights	Constr.	211	6	18	19	2	365
	Other	85	1	6	16	1	
	Total	296	7	24	35	3	
HVAC	Constr.	142	28	49	55	1	454
	Other	107	6	7	57	2	
	Total	249	34	56	112	3	
Solar	Constr.	6	0	35	9	0	91
	Other	3	0	29	9	0	
	Total	9	0	64	18	0	

5. Discussion

The data confirms that the physical safety profile established during the design and construction phases dictates the risks encountered during the subsequent decades of a building's life. For skylights and HVAC systems, the overwhelming majority of incidents - 79.7% and 72.7% respectively - occur during the Operations, Maintenance, and Repair (OM&R) phase. This suggests that current design practices often fail to account for the physical requirements of maintenance personnel, leaving them to navigate built-in structural vulnerabilities, such as unprotected roof openings or poorly positioned electrical panels and machinery, resulting from design optimizations that prioritized initial construction costs over long-term serviceability.

A notable disparity was observed in solar panel incidents, where 71.4% occurred during the "Addition" to existing structures. While this reflects the exponential growth in U.S. solar capacity, the 25-to-30-year lifespan of these systems suggests the current data represents an installation spike. As these systems age, a secondary wave of incidents related to rewiring, cleaning, and eventual replacement is predicted. Proactive design must now address spatial interference, specifically the dangerous proximity between energized solar arrays and other high-maintenance roof elements like HVAC units or fragile skylights, which forces workers into hazardous "buffer zones" during unrelated tasks.

A significant finding of this study is the "classification gap" within national incident reporting. While many victims are categorized under the "Construction" NAICS code, 81.25% of skylight-related and 64.85% of HVAC-related incidents involving these workers were actually maintenance or repair tasks. This suggests that many construction firms are effectively operating as facility service providers, but they are doing so in environments that lack permanent engineering controls, such as integrated fall-arrest anchors or fixed perimeter guarding, which are rarely installed if the building was not designed for frequent maintenance access.

The risk is not limited to construction trades; for HVAC maintenance, nearly 67.9% of victims were employed by non-construction industries. These employers inherit facilities with inherent spatial constraints, such as cramped mechanical rooms or difficult-to-reach ceiling plenums, where the Hierarchy of Controls is often skewed toward less effective measures like PPE. Integrating FM professionals during the design phase provides the "operational intelligence" necessary to identify these physical bottlenecks before they are finalized in the building's structure.

6. Conclusions

This investigation is novel because it focuses solely on maintenance incidents, while previous studies focused primarily to construction. With the analysis of just three building elements (Skylights, solar panels, and HVAC systems) the authors aimed to showcase the need for pre-planning for maintenance safety over the life of a structure. Where previous research has shown that facility managers have concerns for OM&R safety, and have performed facility upgrades in order to address safety concerns [4, 12, 27, 28], this paper quantified the severity of not addressing safety in the planning and design stages. This research demonstrates that safety during a building's occupancy phase is a direct byproduct of design-phase decisions. By analyzing a decade of OSHA investigation summaries, it is clear that:

- Maintenance as the primary risk phase: The vast majority of incidents involving HVAC (72.7%) and skylights (79.7%) occur during routine OM&R, not new construction.

- Element-specific severity: Risks vary significantly by building element. Skylight incidents are profoundly lethal, with a 50.7% fatality rate, while HVAC incidents result in a higher volume of debilitating, non-fatal hospitalizations (67.9%) due to electrical and mechanical hazards in cramped spaces.

- The "Construction" classification gap: Data reveals a significant reporting misalignment; 81.25% of skylight-related incidents and 64.85% of HVAC incidents involved workers categorized under "Construction" who were actually performing maintenance or repair on existing facilities.

- Foreseeable risks in solar evolution: We are currently in an installation-heavy phase for solar, but a shift toward maintenance-related incidents is inevitable as these systems age and interact with existing roof hazards.

To move toward a proactive safety culture, the industry must redistribute risk and responsibility:

- Mandate permanent engineering controls for high-lethality hazards: To address the 50.7% fatality rate associated with skylight falls, designers must move beyond temporary PPE. Building codes should mandate the installation of permanent, factory-integrated skylight screens or perimeter railings during the initial construction phase to eliminate the hazard of fragile walking-working surfaces.

- Design "Safe-Work Zones" for HVAC Systems: To mitigate the high volume of hospitalizations in HVAC maintenance, particularly among the 67.9% of victims who are not construction professionals, designers must provide designated "safe-work zones". This includes ensuring a minimum 36-inch clearance around all mechanical components and providing permanent, fixed-ladder access to all units located in ceiling plenums or rooftops.

- Integrate FM for "Operational intelligence": Because nearly half of skylight incidents (44.2%) involve non-construction employees (such as manufacturing or admin staff), facilities management professionals must be engaged as design consultants. Their operational intelligence is required to identify built-in structural vulnerabilities, such as the dangerous proximity between energized solar arrays and high-maintenance HVAC units, before the building layout is finalized.

- Refine data tracking: National incident reporting must distinguish between "new construction" and "maintenance of existing systems" to provide the granular data needed to update building codes and Design-for-Safety (DfS) standards.

By addressing the specific physical conditions such as fragile surfaces, cramped access points, and system proximity during the design phase, the industry can eliminate the recurring risks that currently define the safety landscape of building operations.

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