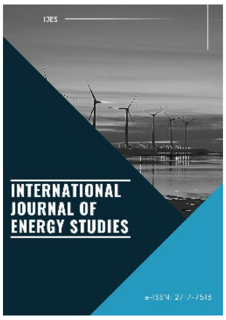
INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-751 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Erratum Article

Int J Energy Studies 2026; 11(2): 1725-1746

DOI: 10.58559/ijes.1982315

Erratum to: Comparative risk analysis of HVAC systems in Turkey in terms of occupational safety

Ganime Tuğba Önder [a*]

[a]Cukurova University, Adana Vocational School, Department of Electricity and Energy, Air Conditioning and Refrigeration Technology Program, Adana, Turkiye, 0000-0002-7504-7394

*(*Corresponding Author: gercoskun@cu.edu.tr)*

In the article titled "Comparative risk analysis of HVAC systems in Turkey in terms of occupational safety", published in Volume 10, Issue 4 of the International Journal of Energy Studies, a formatting problem occurred in the published version of the manuscript.

During the typesetting process, some bibliographic and publication information fields in the manuscript were incorrectly rendered due to formatting issues in the source document. In particular, the page number range in the article information section, the page number range in the citation information and the page number range in the article header section were displayed incorrectly as placeholder text in the published version.

The editorial office reviewed the article and corrected the layout, bibliographic information, citation information, and publication date fields in accordance with the journal's template.

The scientific content of the article remains unchanged. The correction concerns only formatting, bibliographic information, citation display, and header information.

DOI of the article: doi.org/10.58559/ijes.1751613

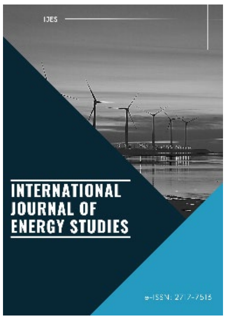
Original article file can be found here: dergipark.org.tr/en/download/article-file/5093713

The corrected version of the article is provided below.

You can cite this erratum as: Onder GT. Erratum to: Comparative risk analysis of HVAC systems in Turkey in terms of occupational safety. Int J Energy Studies 2026; 11(2): 1725-1746.

INTERNATIONAL JOURNAL OF ENERGY STUDIES

e-ISSN: 2717-7513 (ONLINE); homepage: https://dergipark.org.tr/en/pub/ijes



Research Article

Int J Energy Studies 2025; 10(4): 1281-1301

DOI: 10.58559/ijes.1751613

Received : 26 July 2025
Revised : 01 Sep 2025
Accepted : 01 Oct 2025

Comparative risk analysis of HVAC systems in Turkey in terms of occupational safety

Ganime Tuğba Önder [a*]

[a]*Cukurova University, Adana Vocational School, Department of Electricity and Energy, Air Conditioning and Refrigeration Technology Program, Adana, Turkiye, 0000-0002-7504-7394*

*(*Corresponding Author: gercoskun@cu.edu.tr)*

Highlights

- The HVAC industry is classified as hazardous according to occupational health and safety legislation.
- The main risks in the HVAC sector are mechanical, electrical and chemical risks
- Inadequate use of PPE, lack of training, and inadequate emergency plans exacerbate these risks.
- Effective risk assessment has enabled risk reduction.

You can cite this article as: Onder GT. Comparative risk analysis of HVAC systems in Turkey in terms of occupational safety. Int J Energy Studies 2025; 10(4): 1281-1301.

ABSTRACT

This study presents a comparative risk analysis to identify the current and potential risks that HVAC industry workers may be exposed to during system installation or operation. As a result of the assessment conducted using the "L-type (5x5 matrix)" and "Fine-Kinney" methods, it was determined that the HVAC industry in Türkiye is classified as very hazardous and that a more detailed analysis could be conducted using the "Fine-Kinney" method. Furthermore, strategies and solutions were proposed to create a safe work environment and prevent workplace accidents. The study demonstrates that if the necessary precautions are taken, risks can be significantly reduced. The findings will contribute to the strategic assessments of professionals not only in Türkiye but also internationally.

Keywords: HVAC, Occupational health and safety, Risk analysis, L type 5x5 matrix, Fine-Kinney

1. INTRODUCTION

The HVAC sector is a multifaceted sector, operating in key areas such as heating, cooling, ventilation, and plumbing, with a wide range of services ranging from energy systems to automation. The HVAC sector is at a very important point for the efficiency of all other sectors, especially the leading energy, industry, manufacturing, agriculture, food, health and construction fields on the national and international platforms [1]. The sector has a variety of applications, from manufacturing and operations to maintenance and breakdown management and logistics services. Its comprehensive services can be easily integrated with technological developments such as artificial intelligence, smart controls, remote control, and the Internet of Things (IoT) [2]. This rapidly developing field is expected to grow to provide more services in the coming years due to increasing climate change [3,4]. Market analyses for HVAC components predict an average annual growth rate of 6% globally until 2033 [5,6].

Workers in this field perform tasks such as project planning, manufacturing, installation, assembly and disassembly, commissioning, and maintenance and repair. Jobs in this field often require long working hours and significant physical strength. Therefore, employees frequently face dangerous risks. In addition to field-specific physical, chemical, biological, and ergonomic risks, there are many other hazardous situations and risks, particularly those related to combustion and explosion. This makes the air conditioning and refrigeration profession one of the most dangerous occupations. With technological advancements, equipment specific to each field is constantly diversifying, and each new development, while facilitating work, also introduces risks. At this point, it's crucial to understand the industry, its needs, and its equipment, and implement the right match. In this regard, it's crucial for employees and employers to work together. Turkey's sector is in an important position in terms of global exports, with an export volume of $7.2 billion and an import volume of $10.7 billion by 2024[7]. There are approximately 990.000 plumbing and HVAC contracting services across the United States, and 400.000 employees work in air conditioning, mechanical, and installation work [8]. In Turkey, 65 out of every 1.000 workplaces and 45 out of every 1.000 jobs are in the air conditioning and refrigeration sector [9]. The HVAC sector, which contributes significantly to employment and exports, successfully operates on national and international platforms. When we examine the international occupational accident and disease figures, as well as accident figures by sector, in 2025 [10], it is seen that approximately 3 million people lost their lives due to occupational accidents or diseases.

According to the 2024 occupational accident report of the Occupational Health and Safety Assembly, 1.897 people lost their lives in Turkey, with crushing injuries accounting for 18% and falls from heights accounting for 17% [11]. The vast majority of occupational accidents occur due to a lack of attention, inadequate training, and a lack of safety measures [12]. While these figures may not reflect accurate information for the entire field, they underscore the importance of this topic. The educational journey for this profession, which continues to evolve with technological developments, is an ongoing process. Risks inherent in the field always exist, and to act accordingly, they must first be identified. Risk assessments provide an understanding of the causes, consequences, and probabilities of risks. Risk analysis studies have been shown to reduce existing risks in many studies [13,14] and are an extremely important tool for preventing hazards and completely eliminating or controlling potential problems. Regarding this matter, as of January 1, 2025, occupational health and safety (OHS) services were regulated under the Occupational Health and Safety Law No. 6331, covering all lines of business and employers in the public and private sectors. The obligation to have an occupational safety expert inspect the workplace also came into effect for workplaces with fewer than 50 employees and those classified as low-hazard. This obligation now requires risk assessments in all lines of business [15]. Risk analysis practices are conducted under the leadership of occupational safety experts, as stipulated by law. The experts provide detailed tabulation and analysis in the report. However, identifying occupational hazards or determining precautions requires the combined expertise of experts in the field, the experience of employees, and inventory information such as past accident reports—in other words, a team effort. Because in a multidisciplinary field, a single area of expertise will not be sufficient to make accurate determinations. The reporting steps for conducting a risk analysis are as follows:

• Determine the purpose and scope,
• Define risks and determine the risk analysis method,
• Present the current status of the identified risks,
• Determine the possible consequences of identified risks,
• Identify those responsible for each risk definition and identify those affected,
• Providing recommendations for measures to be taken for each risk definition, in accordance with Law No. 6331 and risk-appropriate standards,
• Prioritizing risks and developing strategies for mitigating them,
• Monitoring the process and measures to be taken for each risk, and conducting regular checks and updates.

Identifying occupational hazards and risks, determining who these risks will affect, and their probability can be reduced through analysis and precautions taken. A risk analysis visualizes existing risks like a map. It ensures both the orderly operation of operations and the full fulfillment of legal responsibilities by employers and employees. A well-prepared risk analysis can be used as a guide for employers and employees in the relevant field. The resulting risk scores should be used to implement preventive actions. The measures taken ensure that work proceeds without interruption. In this way, they also protect the work, the worker, and the employer. These precautions must be implemented thoroughly to minimize hazardous situations, foster safety awareness, and minimize damage in the event of an accident. The fact that occupational safety and health procedures are a legal obligation imposed by the government demonstrates that workplaces aim to provide healthy, safe, and prosperous working environments. However, beyond being a legal obligation, establishing a "safety culture" is crucial [16]. The application of risk analysis methods is standard, but such a comprehensive study on the HVAC sector is not available in the literature. This study was conducted to identify the specific risks posed by the HVAC sector and to emphasize the importance of addressing identified risks effectively and in a timely manner. An occupation-specific risk assessment was conducted for applications and field studies in the HVAC sector using the "L-type (5x5 matrix)" and "Fine–Kinney" risk analysis methods. The methods used identify potential risk factors to which workers may be exposed, their probability levels, frequency of occurrence, and strain/impact levels. Identified risks were prioritized to prevent workplace accidents and enhance industry safety. This study compared the effectiveness of analysis methods and also identified measures to protect employees, the work, and the environment to ensure that current risk scores reach targeted levels.

2. MATERIALS AND METHODS

In this study, the "L-type (5x5 matrix) risk analysis method" and the "Fine-Kinney" method were used to analyze and assess risks in the HVAC industry, in accordance with the "TS ISO 31000 risk management" and "TS EN IEC 31010 assessment techniques" standards. When developing a list of hazardous situations for the risk analysis, brainstorming, structured or semi-structured interviews, checklists, root cause analysis techniques, and past accident information were utilized to support the risk analysis argument. In addition, the expertise of an experienced team consisting of an occupational safety specialist, a workplace physician, a plumbing instructor, a mechanical engineer, an electrical engineer, maintenance and operation electrical workshop technicians, a mechanical engineer working in the field of air conditioning and cooling, and air conditioning and cooling technicians was sought. The findings from the risk assessment provide input that businesses can use for their risk management systems. The first step in developing a risk analysis for the HVAC sector is the identification of occupational hazards during the preliminary assessment process. For this risk analysis study specific to the HVAC sector, the following 14 job categories were created: training, documentation, electrical works, split air conditioning and refrigeration, solar energy, oxy-acetylene welding, natural gas works, compressors and pressure vessels, central air conditioning and air ducts, plumbing, sewage-dirty water-wastewater, cold storage facilities, clean rooms, and fire and emergencies. The details for the analysis methods were then applied.

2.1. L-type (5x5 matrix) Risk Analysis Method

The "L-type (5x5 matrix)" risk analysis method is a practical and effective tool widely used today for assessing and managing risks in all areas of activity, both small and large. Two factors are considered when applying this risk analysis method. first factor is the probability of the hazard occurring (Table 1), and the second factor is the severity of the hazard (Table 2). The current status of each risk event is determined numerically using Equation 1. The higher the score, the more serious the risk. The probability and severity of the hazards are assessed using brainstorming, structured or semi-structured interviews, checklists, and root cause analysis techniques, ultimately using Table 3. Based on these results, the identified risks are ranked from largest to smallest and categorized into risk groups. At this point, occupational area-specific numerical limitations can be established. Grouping of risks table (Table 4) is used to plan actions to prioritize critical numbers.

$$Risk\ Skore\ (RS) = Severity\ (S) \times Probability\ (P) \tag{1}$$

When using the probability table, for example, the low value of 2 is selected for the probability that particle release during filter changes will cause reversible respiratory symptoms in the lungs and worsen lung function, and other dust-related lung diseases such as pneumonia (COPD), while the high value of 4 is selected for the probability that power tools will be adjusted or serviced while plugged in.

Table 1. L-type matrix probability scorecard [8]

Probability	Frequency
0	Low and very low (incredible)
1: Very Low	Every five years or more (Very unlikely)

2: Low	Once a year (unlikely)
3: Middle	Once every three months (occasional)
4: High	Once a week (possible)
5: Very High	Every day (frequent)

Table 2. L-type matrix effect (density) chart [11]

Intensity Value	**Ratings**
0	No injuries or illnesses
1: Insignificant	Illnesses and injuries that can be resolved with first aid
2: Minor	Minor injury and illness (Injury and illness causing up to 3 days of work loss)
3: Moderate	Injury and illness causing 3 days or more of work loss
4: Major	Major injury and illness
5: Catastrophic	Death, permanent disability, or similar incapacitating injury

Table 3. L-Type Decision Matrix [16,17]

Risk Score	**Severity**				
Probability	1 (Insignificant)	2 (Minor)	3 (Moderate)	4 (Major)	5 (Catastrophic)
1. (Very Low)	Insignificant Risk	Acceptable Risk	Acceptable Risk	Acceptable Risk	Acceptable Risk
2. (Low)	Acceptable Risk	Acceptable Risk	Acceptable Risk	Moderate Risk	Moderate Risk
3. (Moderate)	Acceptable Risk	Acceptable Risk	Moderate Risk	Moderate Risk	Significant Risk
4. (High)	Acceptable Risk	Moderate Risk	Moderate Risk	Significant Risk	Significant Risk
5. (Very High)	Acceptable Risk	Moderate Risk	Significant Risk	Significant Risk	Unacceptable Risk

Table 4. Grouping of risks [11]

Score	**Degree**	**Description**
15-25	1st Degree	Unacceptable Risk
07-15	2nd Degree	Notable Risk
00-06	3rd Degree	Acceptable Risk

Risk control systems (RCS) must be implemented for the identified first-degree risks and second-degree risks. Measures to be taken for Grade 1 and Grade 2 risks are included in the action plans, specifying the timeframe and responsibilities. Measures to be taken for each risk identified in the analysis are specified with the support of legal regulations. Necessary improvements are made according to the action plan. The target score expected after the measures taken is also created with a triple point system in the planned action evaluation section of the analysis table. This is the stage where high-risk scores are reduced. The following hierarchy is applied when implementing the RCS [11]:

• Eliminating the hazard at its source (e.g., replacing a hazardous substance with a non-hazardous one)

• Reducing the hazard at its source (e.g., replacing a hazardous substance with a less hazardous one)

• Keeping people away from the hazard (e.g., not allowing people to stand or work near construction equipment)

• Containing the hazard (e.g., placing warning signs around the renovation area)

• Reducing worker exposure (e.g., exposing two people to noise for four hours each instead of eight hours for one person)

• Personal Protective Equipment (e.g., gloves, safety glasses, and headgear)

The hazards that exist in the workplace or may come from outside must be identified, the factors that cause these hazards to turn into risks, and the risks arising from these hazards must be analyzed and graded. A risk assessment team is appointed to determine control measures and assign tasks for the work [11]. Reports generated by the team must be kept up-to-date and regularly reviewed. These periodic inspections should be linked to a renewal schedule, as shown in Table 5, based on the hazard class of the work.

Table 5. Renewal periods / year

	Training	**Health**	**Risk Assessment**	**Emergency Action Plan**
High Risk	1	1	2	2
Moderate Risk	2	3	4	4
Low Risk	3	5	6	6

2.2. Fine-Kinney Risk Analysis Method

The Fine-Kinney method is a semi-quantitative risk assessment method frequently used in occupational health and safety and technical risk analyses [18]. As with the L-shaped matrix method, it is used to prioritize risks and determine the urgency of necessary precautions. Unlike the L-shaped matrix method, the criteria include a frequency/exposure score in addition to probability and severity scores (Equation 2).

$$Risk\ Priority\ Number\ (RPN) = \ Severity\ \ x\ \ Probability\ \ x\ Frequency\ (F) \tag{2}$$

Table 6. Fine-Kinney probability score [18]

Probability Value	Probability of Loss Occurring
10	Expected, certain
6	High / very possible
3	Possible
1	Possible but low
0.5	Unlikely but possible
0.2	Unlikely

Table 7. Fine-Kinney frequency [18]

Frequency Value	Frequency:Repeated exposure to a hazard over time
10	Almost constantly (several times an hour)
6	Frequently (once or several times a day)
3	Occasionally (once or several times a week)
2	Not often (once a month or a few times)
1	Infrequently (a few times a year)
0.5	Very rarely (once a year or less often)

Table 8. Fine-Kinney severity [18]

Severity Value	Severity :The estimated harm it will cause to humans and/or the environment
100	Multiple fatal accidents / environmental disaster
40	Fatal accident / serious environmental damage
15	Permanent damage/injury, loss of work / environmental obstruction, complaints from the immediate area
7	Significant damage/injury, external first aid requirement / environmental damage outside the field boundaries
3	Minor damage/injury, internal first aid requirement / limited environmental damage inside the field
1	Close-cut / no environmental damage

Table 9. Fine-Kinney Interpreting / Prioritizing Risk Level [18]

Risk Value	Risk Assessment Result
400 < R	"Intolerable risk; Necessary measures should be taken immediately / or the closure of the facility, building, or environment should be considered."
200 < R < 400	"Substantial risk; Must be remediated in the short term (within a few months)."
70 < R < 200	"Significant risk; Must be remediated in the long term (within a year)."
20 < R < 70	"Possible risk; Must be implemented under supervision."
R < 20	"Insignificant risk; Measures are not a priority."

Table 6 is used to determine the probability score for each risk factor, Table 7 to determine the frequency of exposure to the hazard, and Table 8 to determine the severity of the impact if the event occurs. The risk level and prioritization are then determined using Table 9. control measures are developed based on the risk score. In this method, the more frequently the risk occurs and the greater its impact, the higher the risk score. This score determines the priority at which the risk should be addressed.

3. RESULTS

Within the scope of the study, hazards and risks specific to the HVAC sector across Turkey were identified and analyzed using a 5x5 L-type matrix and the Fine-Kinney method, resulting in risk levels for 200 hazard sources. In the 14 job categories determined for the HVAC industry, separate risk scores were calculated for hazard sources in both analyses. When determining measures to eliminate or minimize the hazard source, the Occupational Health and Safety Law No. 6331 [19] was used as a framework. Additionally, regulations such as the "Regulation on Health and Safety Requirements in the Use of Work Equipment" [20], the "Regulation on the Protection of Workers from the Hazards of Explosive Atmospheres" [21], and the "ISO 45001 – Occupational Health and Safety Management Systems" [22], as well as additional standards such as TS ISO 31000 [23] and TS EN IEC 31010 [24], were utilized. The categorization of the identified risks for the sector is visualized in Figure 1. According to the data, the risks in HVAC systems are fire/explosion (27%), mechanical (21%), and ergonomic (16%). These three categories represent approximately 64% of the total risks. When electrical risks (13.5%) are added to this figure, it becomes clear that approximately 77% of the total risks arise from just four main categories. This finding clearly demonstrates that occupational safety measures in the HVAC sector should be prioritized in these areas. While chemical (12.5%), training and documentation (7.5%), and thermal risks (3%) have lower rates, they are still sources of danger in the field and should not be ignored. Chemical risks, in particular, have critical impacts on employee health due to the use of refrigerants and cleaning chemicals.

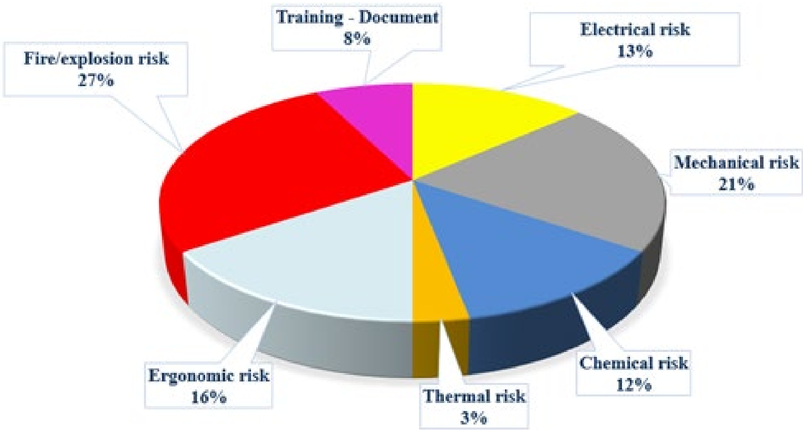


Figure 1. Risk category

In the 5x5 L-type matrix method, the risks calculated based on current risk scores are evaluated and prioritized according to the analysis method. After the measures to be taken are listed, the timeframes allowed for their implementation are defined. Improvements in risk scores resulting from the measures taken are re-evaluated as target scores. If scores are unacceptable, new action plans are created. All risks are periodically monitored throughout the work process to ensure a safe environment. The analysis addresses risks arising from the use of flammable and explosive refrigerants such as NH_3 and R_{32}; risks arising from oxyacetylene, TIG, and electric welding processes used to join metals; natural gas installation activities, cutting, assembly, etc.; working at heights; burn, explosion, and fire risks during manufacturing, assembly, and maintenance activities; compressor explosion risk; and risks associated with electrical work. Working in confined spaces (air ducts, ceiling voids, warehouses) and oxygen deficiency are listed as high-risk groups. Ergonomic risks, exposure to noise, slipping and falling, crushing, and injuries during transportation are listed as medium-risk activities. In the Fine-Kinney method, the risk score (RPN) is calculated by scoring three parameters for each hazard. After determining the risk level, remedial measures are listed and their implementation is monitored. For both methods, if necessary, processes are revised, training is planned, or work is halted. A detailed tabulation of the risk analyses conducted for the 14 work categories identified for the HVAC sector is presented in Annexes 1 and 2.

The numerical distribution of risk scores before and after the methods is presented in Tables 10 and 11, and the graphical representation of this distribution is presented in Figure 2. The distribution of numbers and graphs demonstrate that improvements can be achieved with the applied methods. The outputs from the Fine–Kinney method show that most of the columns, previously colored red as "Intolerable risk (400<R)", were moved to the green as "Insignificant risk (R<20)" after the measures were implemented. The outputs from the L-Type matrix method initially showed "Unacceptable risk (R>20)" and "Significant risk (14<R<20)" levels, but after the measures were implemented, all risks decreased to "Acceptable" and "Insignificant" levels. Because the Fine–Kinney method provides a more detailed ranking, the shift in risks can be more clearly seen. Because the L-Type matrix method assesses risks within a narrower range, risks appear to shift to acceptable levels suddenly, rather than gradually as in the Fine–Kinney method. This is due to the different sensitivities of the two methods.

Table 10. 5x5 L-type matrix risk assessment result distribution

Risk Assessment Result		Before L	After L
20≤R	Unacceptable Risk	87	0
14<R<20	Significant Risk	60	0
7<R≤14	Moderate Risk	53	0
2≤R≤7	Acceptable Risk	0	200
R<2	Insignificant Risk	0	0

Table 11. Fine-Kinney risk assessment result distribution

Risk Assessment Result		Before FK	After FK
400<R	Intolerable risk	166	0
200<R<400	Substantial risk	22	9
70<R<200	Significant risk	8	41
20<R<70	Possible risk	4	67
R<20	Insignificant risk	0	83

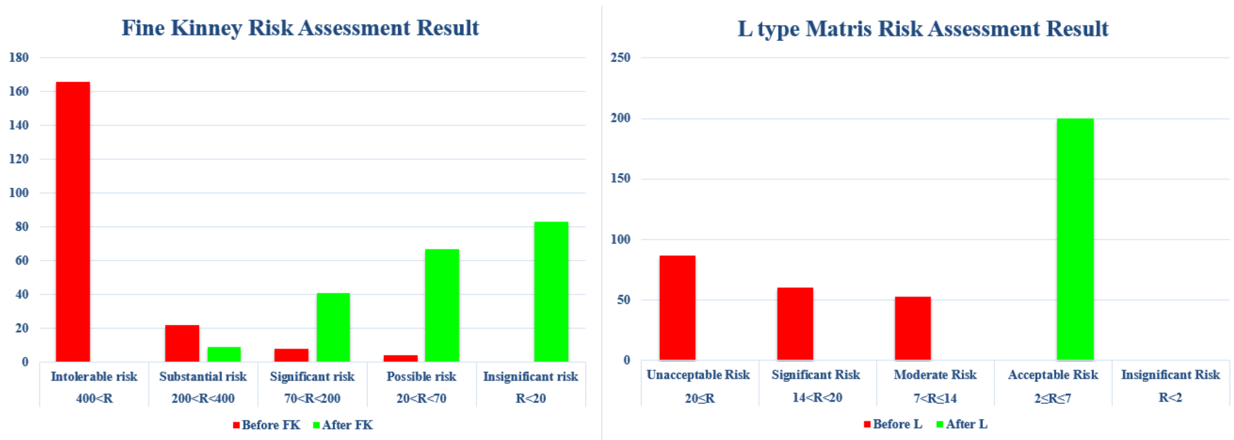


Figure 2. Risk assessment result

The study also examined the cumulative statistical distribution of the identified risks. Separate calculations were made for each method to determine which subcategories constitute 80% of the total risks. The analysis conducted using the L-type matrix method revealed a concentration in the areas of "Split Air Conditioning and Refrigeration," "Electrical Works," "Compressor and Pressure Vessels," and "Fire and Emergency." The analysis conducted using the Fine–Kinney method revealed a concentration in the areas of "Split Air Conditioning and Refrigeration," "Electrical Works," "Oxy-Acetylene Welding," and "Natural Gas Operations." For both methods, "Split Air Conditioning and Refrigeration" and "Electrical Works" ranked first. The comparison of the results of cumulative risk calculations is presented in Table 12. Only cumulative risks common to both methods were used in the tabulation.

Table 12. List of cumulative risks

LIST OF CUMULATIVE RISKS						METHOD:	FİNE KİNNEY				5X5 L TYPE		
							After Taking Measures				After Taking Measures		
No	Category	Risk ID	Department	Activity	Hazard	Risk	P	F	S	RPN	P	S	RS
1	Electrical Works	8	Electric	Electric	Cables with worn insulation	Electric shock	3	3	7	63	1	5	5
2	Electrical Works	9	Electric	Electric	Failure to check the electrical installation	Death	1	2	100	200	1	5	5
3	Electrical Works	10	Electric	Electric	Lack of body grounding of electrically operated machines and equipment	Death	1	2	100	200	1	5	5
4	Electrical Works	11	Electric	Fieldwork	Lighting on and off switches and panels are not closed type (ex-proof) and are not placed in suitable places	Explosion, death	1	2	100	200	1	5	5
5	Electrical Works	12	Electric	Fieldwork	Not using fireproof cable	Injury, death	1	2	40	80	1	4	4
6	Electrical Works	13	Electric	Fieldwork	Electrical breaker emergency stop not working	Injury, death	1	1	100	100	1	5	5
7	Electrical Works	14	Electric	Fieldwork	The electrical system breaker emergency stop button is not in a suitable and accessible place	Injury, electric shock	1	2	40	80	1	4	4
8	Electrical Works	15	Electric	Electric	Damage to cables due to stepping on them or placing materials on them	Electric shock	1	1	100	100	1	5	5
9	Electrical Works	18	Electrical Panels	Electric	Improper and unsafe layout of extension cords in the workplace	Falls, injuries, electric shocks due to employees tripping	1	1	100	100	1	5	5
10	Electrical Works	22	Electrical Panels	Electric	Lack of insulating mat in front of the panel	Electric shock, injury, death	1	0.5	100	50	1	5	5
11	Electrical Works	23	Electrical hand tools	Fieldwork	Use in damp and wet places	Electric shock, injury, death	1	1	100	100	1	5	5
12	Electrical Works	26	Electrical hand tools	Fieldwork	Lack of attention in gas systems: failure to consider the properties of the gas used in electrical installations, lighting, heating/cooling systems	Electric shock, drowning, death	1	1	100	100	1	4	4

13	Electrical Works	28	Emergency	General	Lack of external access to emergency shutdown controls in the event of gas leakage or emergency conditions	Electric shock, drowning, death	1	1	100	100	1	4	4
14	Electrical Works	29	Warning/Caution Sign	General	Absence of safety signage resulting in failure to detect the danger and causing electric shock	Serious injury, death	1	1	100	100	1	5	5
15	Split Air Conditioning and Refrigeration	33	Installation/Maintenance/Repair	Fieldwork	Dangerous behaviors	Work accident	3	3	7	63	1	5	5
16	Split Air Conditioning and Refrigeration	34	Manual material handling	Fieldwork	Manual handling of air conditioning indoor and outdoor units and equipment	Injury, waist and back disorders, musculoskeletal system problems, occupational diseases	3	6	15	270	1	4	4
17	Split Air Conditioning and Refrigeration	35	Manual material handling	Fieldwork	Manual handling of welding equipment	Injury, waist and back disorders, musculoskeletal problems, occupational diseases	3	6	15	270	1	4	4
18	Split Air Conditioning and Refrigeration	36	Installation/Maintenance/Repair	Fieldwork	Falling of material	Head and foot injuries caused by falling objects	3	6	15	270	1	4	4
19	Split Air Conditioning and Refrigeration	38	Installation/Maintenance/Repair	Fieldwork	Nitrogen cylinder explosion during nitrogen injection used for system cleaning	Explosion, injury, loss of limb, death	1	0.5	100	50	1	5	5
20	Split Air Conditioning and Refrigeration	39	Chemicals	Fieldwork	Use of flammable and explosive refrigerants such as R_{32}	Explosion, injury, loss of limb, death	1	1	100	100	1	5	5
21	Split Air Conditioning and Refrigeration	40	Installation/Maintenance/Repair	Fieldwork	Burn hazard due to leakage in the central heating coil line	Explosion, injury, loss of limb, death	1	0.5	100	50	1	5	5
22	Split Air Conditioning and Refrigeration	43	Installation/Maintenance/Repair	Fieldwork	Application of refrigerants in direct expansion HVAC systems	Due to its toxic and irritating effects, it can cause spasms in the lungs, lead to edema, or, depending on the concentration inhaled, cause health problems such as a burning sensation, headache, and fainting. Excessive inhalation can lead to death	3	3	7	63	1	4	4
23	Split Air Conditioning and Refrigeration	46	Working at height	Fieldwork	Falling during indoor and outdoor unit installation (falling from a height of 2-3 meters) or working on a ladder	Injury, work accident	3	2	7	42	1	4	4
24	Split Air Conditioning and Refrigeration	47	Working at height	Fieldwork	Falling during indoor and outdoor unit installation (falling from high buildings or roof height)	Injury, death	3	1	40	120	1	5	5
25	Split Air Conditioning and Refrigeration	49	Chemicals	Fieldwork	Unsafe use of chemicals (solvents, olbrayt, etc.). Contact with chemicals while cleaning.	Serious poisoning, injury, and risk of permanent vision loss from eye contact. Dizziness and nausea from inhaling Olbrayt vapors. Risk of gas accumulation in enclosed	3	3	7	63	1	4	4

						spaces. Working with Olbrayt without wearing protective clothing. Splash from use of improper spray equipment. Workplace accidents and occupational illnesses							
26	Split Air Conditioning and Refrigeration	50	Chemicals	Fire	Unsafe use of chemicals (solvent, olbrayt, etc.), fire hazard due to contact of olbrayt with flammable materials	Injury, death	1	1	100	100	1	5	5
27	Split Air Conditioning and Refrigeration	51	Chemicals	Fieldwork	Risks that may arise from gas charge and discharge leaks. Especially cold burns	Frostbite can cause the hand to freeze; if forcefully pulled, the skin and flesh may tear away from the bone	3	2	15	90	1	4	4
28	Split Air Conditioning and Refrigeration	58	Installation/Maintenance/Repair	Fieldwork	Use of R_{600} gas in refrigerator operations	Explosion, loss of limb, injury, death, fire	1	1	100	100	1	5	5
29	Split Air Conditioning and Refrigeration	59	Installation/Maintenance/Repair	Fieldwork	Inhalation of gas due to gas leakage (refrigerant) in refrigerator operations	Drowning, injury, death, fire	1	1	100	100	1	5	5
30	Split Air Conditioning and Refrigeration	60	Installation/Maintenance/Repair	Fieldwork	In refrigerator operations, heavy load carrying	Injury, waist and back disorders, musculoskeletal problems, occupational diseases	3	3	7	63	1	4	4
31	Split Air Conditioning and Refrigeration	61	Installation/Maintenance/Repair	Fieldwork	Explosion due to high pressure in refrigerator operations	Explosion, injury, death	1	0.5	100	50	1	5	5
32	Split Air Conditioning and Refrigeration	63	Installation/Maintenance/Repair	Fieldwork	Oxygen cylinder explosion during the assembly of system elements in refrigerator operations	Explosion, injury, loss of limb, death	1	0.5	100	50	1	5	5
33	Solar Energy	65	Working at height	Fieldwork	Working at height, falling from high buildings or roof height during assembly	Injury, death	3	1	40	120	1	5	5
34	Solar Energy	66	Installation/Maintenance/Repair	Fieldwork	Falling of material	Head and foot injuries caused by falling objects	3	3	15	135	1	4	4
35	Oxy-Acetylene Welding	69	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Fire	Due to its high explosiveness when mixed with air in specific ratios, acetylene gas presents a significant hazard. The storage of gas cylinders in enclosed spaces increases the risk of explosion in case of a fire	Explosion, injury, loss of limb, death	1	0.5	100	50	1	5	5
36	Oxy-Acetylene Welding	70	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Storage	Due to the lack of warning and information signs in the storage area, employees approaching the environment with a caustic substance may cause an explosion	Explosion, injury, loss of limb, death	1	0.5	100	50	1	5	5
37	Oxy-Acetylene Welding	71	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Fieldwork	Failure to secure flammable and explosive gas cylinders, risk of tipping over	Fire, explosion, injury, death	1	0.5	100	50	1	5	5

38	Oxy-Acetylene Welding	72	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Storage	Storing flammable and explosive cylinders in the same place	Fire, explosion, chain reaction, injury, death	1	0.5	100	50	1	5	5
39	Oxy-Acetylene Welding	73	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Fieldwork	Lack of periodic inspection and testing of cylinders, valves and other gas equipment	Fire, explosion, injury, death	1	1	100	100	1	5	5
40	Oxy-Acetylene Welding	74	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Fire	Lack of fire extinguishers for emergency response to fire in the area where the cylinders are stored	Fire, explosion, injury, death	1	1	100	100	1	5	5
41	Oxy-Acetylene Welding	75	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Fieldwork	Oxygen-Gas welding process used to join metals	Fire, explosion, injury, death	1	1	100	100	1	5	5
42	Oxy-Acetylene Welding	76	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Welding Fumes	Hazards such as steam, dust, etc., generated during the use of substances (Cadmium, Copper, Silver, Zinc) to be added to the mixture to be used in the welding setting	Respiratory tract disease-Eye disease	3	3	15	135	1	4	4
43	Oxy-Acetylene Welding	77	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Leaks	Gas leaks	Leaks that may occur in gas connections may cause explosion and fire	1	1	100	100	1	5	5
44	Oxy-Acetylene Welding	78	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Explosion	Incorrect gas pressure	Acetylene becomes unstable at pressures above 1.5 bar and the risk of explosion increases	1	0.5	100	50	1	4	4
45	Oxy-Acetylene Welding	79	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Fire	Sparks arising during welding or contact of hot materials with flammable materials	Fire, explosion, injury, death	3	1	100	300	1	5	5
46	Natural Gas Operations	80	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Fieldwork	Tungsten Inert Gas (TIG) welding process used to join metals	Fire, explosion, injury, death	3	1	100	300	1	5	5
47	Natural Gas Operations	81	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Leaks	Gas leaks	Leaks that may occur in gas connections may cause explosion and fire	1	1	100	100	1	5	5
48	Natural Gas Operations	82	Installation/Maintenance/Repair	Fieldwork	Lack of a gas leakage notification system in gas-powered systems	Fire, explosion, injury, death	1	1	100	100	1	5	5
49	Natural Gas Operations	83	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Explosion	Incorrect gas pressure	Acetylene becomes unstable at pressures above 1.5 bar, increasing the risk of explosion. (Cylinders must be properly regulated)	1	0.5	100	50	1	4	4
50	Natural Gas Operations	84	Storage and Use of Oxygen, Acetylene or LPG Cylinders in Welding Works	Fieldwork	Gas leakage notification system not working in gas powered systems	Fire, explosion, injury, death	1	1	100	100	1	5	5
51	Natural Gas Operations	85	Welding Works	Fieldwork	Welding gas	Fire and explosion due to improper use of flammable and explosive gases	1	1	100	100	1	4	4
52	Natural Gas Operations	86	Installation/Maintenance/Repair	Fieldwork	Natural gas installation activities, cutting, assembly etc.	Leakage and explosion due to incorrect applications	1	1	100	100	1	5	5

53	Natural Gas Operations	87	Fire	Fire	Lack of firefighting equipment in proper condition	Inadequate response to fire, burning, burns, serious loss of life and property	1	1	100	100	1	4	4
54	Compressor and Pressure Vessels	89	Compressor	Fieldwork	Compressor explosion	Work accident, injury, death, etc.	1	0.5	100	50	1	4	4
55	Compressor and Pressure Vessels	93	Boiler Room	Fieldwork	High noises from burners, pumps, fans and other equipment in boiler rooms	Tinnitus and permanent hearing loss	3	1	15	45	1	4	4
56	Compressor and Pressure Vessels	95	Boiler Room	Fieldwork	Use of the boiler room by unauthorized persons and intervention of these persons to the boiler	Death from boiler explosion	1	1	100	100	1	5	5
57	Compressor and Pressure Vessels	97	Boiler Room	Maintenance and Repair Works	Maintenance and repairs not carried out by authorized personnel, failure to take necessary precautions in case of malfunction, use of inappropriate hand tools, failure to use PPE, and failure to identify unused devices	Work accidents with loss of life and property, fire, explosion	1	3	15	45	1	5	5
58	Compressor and Pressure Vessels	98	Boiler Room	Maintenance and Repair Works	LPG leak in LPG-fired burners with initial ignition (safety, feed, and circulation systems)	Explosion and fire hazard due to LPG leakage	1	1	100	100	1	5	5
59	Compressor and Pressure Vessels	99	Boiler Room	Electric	Operation with high voltage (10.000 Volts) in ignition transformer and electrode circuit	Work accidents causing loss of life and property, fire, explosion	3	3	15	135	1	5	5
60	Compressor and Pressure Vessels	102	Boiler Room	Maintenance and Repair Works	Injuries and body crushing caused by contact with rotating pump and fan shafts during operation	Injuries resulting from contact with pump and fan shafts	3	1	40	120	1	4	4
61	Sewerage, Dirty Water, Waste Water	162	Installation/Maintenance/Repair	Fire	Fire in confined spaces	Explosion, injury, death	3	2	40	240	1	5	5
62	Sewerage, Dirty Water, Waste Water	163	Installation/Maintenance/Repair	Emergency	Emergency in confined spaces	Explosion, injury, death	3	2	15	90	1	5	5
63	Clean Rooms	178	Installation/Maintenance/Repair	Fieldwork	Failure to use appropriate personal protective equipment (PPE)	Work accident, injury, fall, loss of limb, death	3	2	15	90	1	5	5

The targeted reductions in existing risk scores resulting from the implementation of the listed measures in designated work areas within the HVAC sector are shown in Figure 3. The red lines in the graphs represent the initial risk values, while the green lines represent the targeted risk scores or the risk scores after the measures were implemented. Significant reductions in initial risk scores were observed following the measures taken. The Fine–Kinney method, due to its technically more parameters, produced higher scores, a wider distribution, and high peaks. Following the measures, most risk scores were reduced to the 20-70 range and below. In the L-type matrix method, before the measures were implemented, risks were concentrated in the 10-20 range and were mostly at high levels. However, thanks to the measures taken, risks were reduced to 5 and below. The graphs reflect the successful results of the risk analysis and demonstrate that occupational accidents are manageable and preventable when appropriate measures are taken. They also clearly indicate which hazard definitions have been significantly improved or need to be improved.

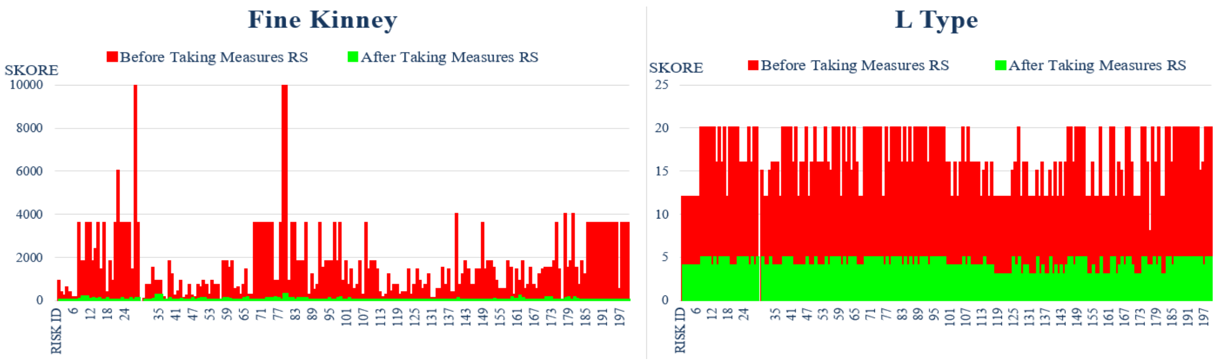


Figure 3. Results of the hazard and risk evaluation

4. CONCLUSION

Risk analysis studies are a technical tool used for workplace inspections and monitoring systems. Occupation-specific analyses, on the other hand, allow risk assessment processes to be tailored to the specific conditions, needs, and risks of the sector. This allows for the implementation of risk analysis methods beyond a general framework and prevents risks and hazards from being overlooked. This study identified hazards arising from installation, maintenance, and repair activities in the HVAC sector in Türkiye, and conducted two different risk assessments aimed at creating safe working environments for employees, the workplace, and the environment. This study is the first comprehensive risk assessment study conducted for installation, maintenance, and repair activities in the HVAC sector. Within the scope of the analysis study, 14 sub-fields of work were identified in the HVAC sector. The hazards identified within these 14 sub-categories were developed using the opinions of experienced individuals, structured or semi-structured interviews, checklists, root cause analysis, and past accident information. A total of 200 risks were identified for 14 work sites, and a comparative analysis was conducted using the "5x5 L-type matrix" and "Fine-Kinney" analysis methods. The aim here is to identify potential risks in HVAC workspaces, identify their consequences, and reduce their likelihood in the future. Every measure taken serves as a safety mechanism that prevents serious injuries and deaths by both protecting employees' lives and ensuring the sustainability of the industry. This analysis provided an effective analysis that supports HVAC process management to prevent or minimize loss of life and damage.

Fire/explosion (27%), mechanical (21%), and ergonomic risks (15.5%) constituted the three main hazard groups that stood out in the industry. This inference facilitates prioritization of action plans and more efficient use of resources. Using the L-type matrix method, 147 risks were classified as high risk and 53 as medium risk. The total score of the identified risks decreased from 3322 to 865, a reduction of approximately 73.98%. Using the Fine-Kinney method, 188 were classified as high risk and 12 as medium risk. The total score of the identified risks decreased from 345696 to 9958, a reduction of 97.12%. The priority areas, common to both analyses, were "Split Air Conditioning and Refrigeration" and "Electrical Works." The main factors that highlight these areas are the frequency of risk occurrence and their degree of impact. The Fine-Kinney method is suitable for a more detailed risk assessment, while the L-type matrix method can be used for quick and practical decision-making in the field. The study revealed that HVAC workers are exposed to high risks and that significant reductions in risk scores can be achieved if the necessary precautions are taken. These measures will establish a solid safety foundation that will protect employees from conditions that threaten occupational health and ensure they work in a safe environment. Occupational safety training and the use of industry-appropriate personal protective equipment (PPE) should be a priority in risk reduction efforts. While risks can be prioritized within the scope of occupational safety and health, it is essential that all risks be treated with equal care and attention to prevent not only occupational accidents but also loss of life and property in the sector. If deficiencies are identified, employers must be ensured to fulfill their legal obligations, and if necessary, penalties should be imposed. Occupational safety measures not only protect employee rights but also contribute to public health and ensure a productive workforce. The conducted risk analysis can be successfully used as a guide to contribute to risk management activities in the HVAC sector. This analysis provides a framework for understanding occupational risks and their potential impacts. Risk assessment is not a stand-alone activity, but rather an important support mechanism that must be incorporated into the risk management process. Risk analysis should be periodically updated and detailed in light of technological advancements and new methods. Changing conditions should be reflected in the risk analysis without delay, and employees should be trained on all occupational safety-related risks. Effective preparation and implementation of risk analyses is vital for the HVAC sector, which holds a significant place in national and international platforms. Preventing occupational accidents and creating safe working environments plays a critical role in the sustainability of the HVAC sector. In the assessment and implementation stages of sectoral risks, a joint study should be carried out by taking into account the opinions of experts from different fields, as in this study, and different risk assessment methods should be used together to increase the effectiveness of the analysis.

ACKNOWLEDGMENT

I would like to express my sincere thanks to “Class A Occupational Safety Specialist” Mr. Mehmet Ergin Önder; “Adana Kızılay Blood Donation Center Director” Dr. Turgut Karaca; Mechanical Engineer and Lecturer Mr. Erdoğan Şimşek from the “Cukurova University HVAC and Refrigeration Technology Program”; Mechanical Engineers Mr. Bülent Doğan, Mr. Selçuk Yapıcı, and Mr. Emrah Cengiz, technicians at the electrical workshop of the “Çukurova University Directorate of Construction and Technical Affairs”; Mechanical Engineer Mr. Murat Şahin, supervisor of the “Cukurova University Central Heating Plant”; and retired Electrical Control Engineer Mr. Adnan Basalak from the same directorate. I also extend my personal gratitude to HVAC Technician and company owner Mr. Mustafa Güngör; Mechanical Engineer Mr. Ufuk Emre Şeker; HVAC Technician and “Kaya Plumbing” company owner Mr. Velat Kaya; HVAC Technician and “Ufuk Technical Cooling” company owner Mr. Ufuk Tiyer; and “Samsung” Technical Support Specialist Mr. Ferit Sönmez for their valuable assistance in their fields of expertise and their contributions to the HVAC field.

DECLARATION OF ETHICAL STANDARDS

The author of the paper submitted declares that nothing which is necessary for achieving the paper requires ethical committee and/or legal-special permissions.

CONTRIBUTION OF THE AUTHORS

Ganime Tugba Onder: Conducted the risk analysis and wrote the article.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

REFERENCES

[1] Mawson VJ, Hughes BR. Optimisation of HVAC control and manufacturing schedules for the reduction of peak energy demand in the manufacturing sector. Energy 2021; 227:120436.

[2] Devaraj SM. The future of HVAC systems: AI, cloud, and the Internet of Things (IoT). Technology (IJCET) 2023; 14(2):269-2780.

[3] ISKID – Air Conditioning and Refrigeration Manufacturers’ Association. ISKID 2023 air conditioning industry statistical results. 2023. Available from: https://iskid.org.tr/iskid-2023-iklimlendirme-istatistik-sonuclari/. Accessed: February 1, 2025. [Online].

[4] ISIB – Turkish HVAC-R Exporters Association. ISIB announces mid-year report of the HVAC sector. 2024. Available from: https://isib.org.tr/2024/08/01/isib-iklimlendirme-sektorunun-ilk-yari-karnesini-acikladi/. Accessed: February 1, 2025. [Online].

[5] Raje K. HVAC Components Market Report 2025 (Global Edition), Edition: 8th, Report ID: CMR802657, Data Updated: May 2025.

[6] Precedence Research. HVAC System Market Size and Forecast 2025 to 2034. Available from: https://www.precedenceresearch.com/hvac-system-market. Last Updated: 11 Jul 2025. Report Code: 4221. Category: Machinery and Equipment. Accessed: July 23, 2025. [Online].

[7] T.C. ACSA. Republic of Turkey Ministry of Trade, Air Conditioning Sector Analysis. Available from: https://www.kolayihracat.gov.tr/sektorler/iklimlendirme. Accessed: July 23, 2025. [Online].

[8] ConsumerAffairs. HVAC industry statistics 2025 [2024]. ConsumerAffairs.com. Apr. 16, 2024. Available from: https://www.consumeraffairs.com/homeowners/hvac-industry-statistics.html. Accessed: July 23, 2025. [Online].

[9] TSEC VIII – Türkiye Sectoral Economic Council. TOBB Publication Number: 2015/248. ISBN No: 978-605-137-366-9. Available from: https://www.tobb.org.tr/Documents/yayinlar/2015/8Sektorel-Ekonomi-Surasi.pdf. Accessed: July 23, 2025. [Online].

[10] ILO – International Labour Organization. Safety and health at work: Global trends and statistics – 2025 update. Geneva: ILO. Available from: https://www.ilo.org/global/topics/safety-and-health-at-work. Accessed: July 23, 2025. [Online].

[11] Workers' Health and Work Safety Assembly (İSİG). 2024 occupational accident report 2024.

[12] Küçükaslan Y. Work accidents and occupational safety. ISK Technical Journal, September–October Issue, Asal HVAC Technologies Inc., After-Sales Services Manager, October 30, 2015.

[13] Ceylan H, Başhelvacı VS. Risk analysis with risk assessment table method: a case study. International Journal of Engineering Research and Development 2021; 3(2):25–33.

[14] Önder GT, Külekci MK. Vaporizing foil actuator welding prototype manufacturing and applications risk analysis. Niğde Ömer Halisdemir University Journal of Engineering Sciences 2023; 12(4):1–1.

[15] Ministry of Labor and Social Security of the Republic of Türkiye. Frequently asked questions – Directorate General of Occupational Health and Safety. Available from: https://www.csgb.gov.tr/sikca-sorulan-sorular/is-sagligi-ve-guvenligi-genel-mudurlugu/. Accessed: July 23, 2025. [Online].

[16] Önder ME. The effects of legal regulations on noise and vibration on the work efficiency of employees in different sectors. Master's thesis, Çukurova University, 2019.
[17] Önder ME. Hazard and risk assessment procedure [Personal training notes]. İSG Doctor Joint Health and Safety Unit, Mersin, 2025.
[18] Ak MF. Comparison of risk assessment methods within the scope of occupational safety in the construction sector. European Journal of Science and Technology 2020; (18):272-282.
[19] Republic of Türkiye. Law No. 6331 on Occupational Health and Safety. Official Gazette No. 28339, June 30, 2012. Available from: https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=6331&MevzuatTur=1&MevzuatTertip=5. Accessed: August 30, 2025. [Online].
[20] Ministry of Labor and Social Security of the Republic of Türkiye. Regulation on Health and Safety Conditions in the Use of Work Equipment. Official Gazette No. 28628, April 25, 2013. Available from: https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=18318&MevzuatTur=7&MevzuatTertip=5. Accessed: August 30, 2025. [Online].
[21] Ministry of Labor and Social Security of the Republic of Türkiye. Regulation on the Protection of Workers from the Hazards of Explosive Atmospheres. Official Gazette No. 28633, April 30, 2013. Available from: https://www.mevzuat.gov.tr/mevzuat?MevzuatNo=18335&MevzuatTur=7&MevzuatTertip=5. Accessed: August 30, 2025. [Online].
[22] International Organization for Standardization (ISO). ISO 45001:2018 Occupational health and safety management systems — Requirements with guidance for use. Geneva: ISO, 2018.
[23] Turkish Standards Institution (TSE). TS ISO 31000: Risk management — Principles and guidelines (1st ed.). Ankara: TSE, 2014.
[24] Turkish Standards Institution (TSE). TS EN IEC 31010: Risk management — Risk assessment techniques (2nd ed.). Ankara: TSE, 2021.