

From Fume Capture to Exposure Reduction: Local Exhaust Ventilation (LEV) Performance in Welding Bays - A Scoping Review

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ABSTRACT

Local exhaust ventilation (LEV) can control welding emissions at source, but installation alone does not demonstrate reduced worker exposure. This scoping review maps the extent, characteristics and measurement approaches of welding-LEV evidence published from 1997 to 2026. The review question was structured using the Population-Concept-Context framework and covered welders and adjacent workers; LEV performance and exposure verification; and laboratory, training and industrial welding settings. Sources were identified through iterative searches of PubMed, publisher platforms and institutional repositories, supplemented by backward and forward citation searching. Thirty-two primary sources were charted across engineering and modelling, controlled or comparative exposure, workplace observational or intervention, and exposure-characterisation or biomonitoring evidence. Performance depended on source-hood distance, induced velocity, welding orientation, emission rate and work practice. Comparative studies generally reported reductions in manganese, total particulate and hexavalent chromium under defined conditions, whereas workplace effects were smaller or more variable. Heterogeneous outcomes were mapped by evidence stratum and were not statistically pooled. The map identifies a persistent gap between engineering capture measurements and matched personal breathing-zone evidence, particularly for bystanders and across maintenance cycles. LEV protection should therefore be verified during representative work rather than inferred from equipment presence alone.

Keywords: Welding; Local Exhaust Ventilation; Occupational Exposure; Environmental Monitoring; Occupational Health; Scoping Review

INTRODUCTION

Welding-bay safety depends on whether control measures reduce the contaminants reaching workers during routine production. Earlier studies established that extraction airflow, hood position, welding orientation and task context govern source capture [26-34]. More recent workplace evidence shows that exposure and control provision still vary substantially, even where ventilation is nominally available [1,2,11]. Local exhaust ventilation (LEV) captures contaminants near their source before they disperse into surrounding air. Its performance can nevertheless be described using different outcomes: collected fume, concentration near the arc, concentration in the breathing zone, or exposure across an entire shift. Controlled comparisons of industrial extraction arrangements and a study of an extraction-equipped tungsten inert gas (TIG) torch provide evidence of reduced airborne concentrations under specified test conditions [3,4]. A recent workplace prevention study extends the question to manual welders, robot operators and bystanders, while illustrating the difficulty of separating ventilation effects from a broader intervention programme [5]. The health rationale for preventing welding-fume exposure is supported by contemporary syntheses of lung-cancer and human-biomonitoring evidence [6,7]. However, reviewing health hazards alone does not resolve how ventilation should be evaluated. A device may collect substantial fume while the worker's position permits residual

emissions to cross the breathing zone. Conversely, a low concentration during a short measurement period may reflect low welding activity rather than effective extraction. A scoping-review design is appropriate because the literature spans diverse study designs, settings, contaminants and endpoints and the purpose is to map how LEV has been evaluated rather than estimate one pooled treatment effect [42,43]. The review asks: what types of evidence have been used to evaluate welding-bay LEV, which conditions and measurements are associated with exposure reduction, and where are the principal evidence gaps? Its objectives are to distinguish capture outcomes from exposure outcomes, map the development of measurement approaches, describe design-specific interpretive limitations and formulate priorities for realistic welding-bay evaluation.

SCOPING REVIEW METHODS

Review design, question and scope

This evidence-mapping scoping review was informed by JBI methodological guidance and reported against applicable PRISMA-ScR items [42,43]. The Population-Concept-Context framework comprised: populations of welders, robot operators, trainees, bystanders and adjacent workers; the concept of welding-LEV design, capture performance and exposure verification; and laboratory, educational, fabrication, construction, refinery, shipbuilding and confined-space contexts. Publications dated from 1 January 1997 to 4 September 2026 were considered. The broad scope was selected to show how engineering capture evidence connects, or fails to connect, with personal, spatial and biological exposure outcomes. The review was not designed to calculate a pooled causal effect of LEV. No protocol was registered prospectively. Because complete record-level logs from the original iterative searches were not retained, the manuscript does not claim full PRISMA-ScR compliance and does not present an unreconstructable screening flow diagram.

Information sources and search approach

Iterative searches were completed up to 4 September 2026 in PubMed, publisher platforms and institutional repositories. Backward and forward citation searching began with the welding-LEV review by Flynn and Susi [37] and continued from eligible sources. Exact titles and digital object identifiers were verified against publisher or indexing records. Search concepts combined weld* or arc welding with local exhaust ventilation, LEV, fume extraction, on-gun extraction or extraction torch, and with exposure, breathing zone, fume, manganese, chromium, ultrafine particle, ozone, capture efficiency or airflow. The concept blocks and date range are reported so that the map can be updated, but the sources were searched iteratively rather than through one identical platform-specific string. Scopus and Web of Science were not searched systematically. Search reporting was assessed with PRISMA-S principles, and this database limitation is carried into the interpretation [44]. Eligible primary sources examined welding-related LEV design or performance, comparative exposure reduction, or a measurement pathway relevant to control verification. Laboratory experiments, workplace studies, engineering measurements, numerical models, particle or gas monitoring and biomonitoring were eligible. Clinical studies without a ventilation-performance question, unrelated ventilation research and unsupported product claims were excluded. Malaysian legislation, official guidance and industry documents were retained only as contextual sources. Abstract-only records were eligible when directly relevant, but their contribution was restricted to information stated in the accessible record.

Source selection and accounting

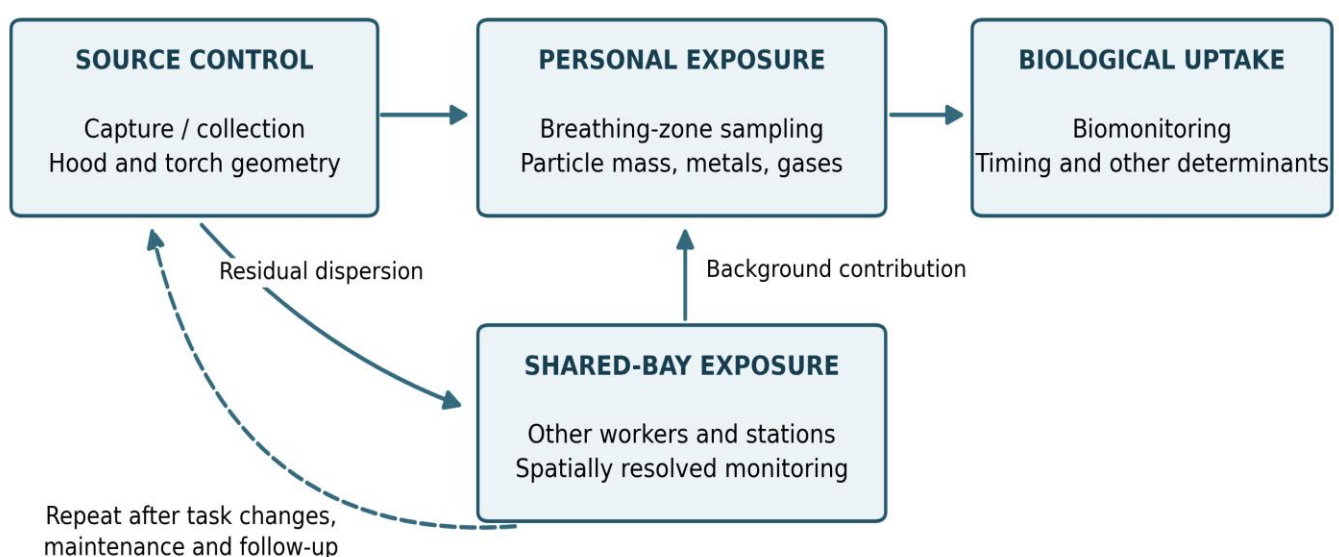
Potentially relevant titles and abstracts were assessed against the eligibility criteria, followed by full-record assessment when accessible. The final evidence map contains 32 primary sources: surveys and workplace monitoring, experimental comparisons, engineering and airflow studies, numerical modelling, particle or gas characterisation and biomonitoring. Three review sources were used to establish health context or support citation searching [6,7,37], and six legal, technical or industry documents were used only for Malaysian implementation context [20-25]. These contextual items were not counted as primary evidence of LEV effectiveness. Complete counts for records identified, deduplicated and excluded at each screening stage cannot be recovered from the original iterative search process; inventing those values would create false precision. This departure from PRISMA-ScR is explicitly acknowledged in the limitations.

Data charting and critical-appraisal boundaries

A structured charting framework captured study design and setting, welding process and material, LEV configuration, comparator, sampling location, endpoint, averaging period, unit of analysis, respiratory-protection context and principal finding. Charted sources were grouped iteratively as the map developed. Because scoping reviews primarily describe the extent and characteristics of evidence, a formal risk-of-bias score and certainty grade were not used [42,43]. Instead, design-specific critical-appraisal boundaries were recorded to prevent unlike sources from being interpreted as equivalent. Experimental studies were examined for comparator equivalence, source-condition control, replication, observation independence and outcome location. Workplace studies were examined for selection, baseline comparability, task and material differences, confounding, concurrent controls, repeated measurements and LEV-specific attribution. Modelling studies were examined for boundary conditions, measurement validation and transferability. Exposure-characterisation and biomonitoring studies were examined for sampling position and timing, endpoint specificity, background exposure, respiratory protection and linkage between LEV status and measured outcome. Abstract-only sources were assigned greater interpretive uncertainty. Tables I and II present the mapped contribution and principal appraisal boundary of each source rather than a numerical quality ranking.

Evidence mapping and synthesis

Evidence was mapped in four strata: (1) engineering and modelling studies of airflow, capture and system behaviour; (2) controlled or comparative studies measuring fume or metals with and without defined extraction arrangements; (3) workplace observational or multi-component intervention studies; and (4) exposure-characterisation and biomonitoring studies. The strata were treated as complementary stages along the source-to-dose pathway, not as equivalent estimates of one effect. Findings were summarised descriptively by design, setting, outcome and appraisal boundary. Meta-analysis was outside the mapping objective and was also technically inappropriate because sources used incompatible outcomes, contaminants, sampling fractions, welding processes, ventilation comparators, averaging periods and units of analysis. Several reports used small repeated samples that were not independent, while respiratory protection separated ambient concentration from inhaled dose. Figures 2-5 therefore visualise selected published results descriptively; they are not pooled or certainty-weighted effect estimates. Figure 1 presents the framework used to relate the four evidence strata.



INTERPRETATION: match the measurement to the claim

Fig. 1. Proposed framework linking source capture to exposure verification.

Table I. Recent evidence informing LEV performance and exposure verification, with design-specific appraisal boundaries.

Study	Design / setting	Main endpoint or contribution	Critical-appraisal boundary
Fritschi et al. (2024) [1]	Occupational online survey; Australia	Control provision and questionnaire-assessed exposure	Implementation context; no measured LEV effect
Driscoll et al. (2026) [2]	Monitoring in 20 Australian workplaces	Workplace exposure and ventilation arrangements	Observational; task and site differences
Knott et al. (2023) [3]	Experimental comparison of industrial controls	Total fume and metals across controls	Small cells; repeated sampling; PAPR context
Kővágó et al. (2025) [4]	Conventional versus extraction TIG torch	Breathing-zone nanoparticle concentration	Additional torch extraction; background ventilation
Assenhøj et al. (2026) [5]	Two-company prevention programme	Air and biomonitoring across worker groups	Combined intervention; abstract-limited appraisal
Egerland et al. (2023) [8]	Experimental technical-control investigation	Emission and exposure under welding conditions	Interacting measures; abstract access
Kuppusamy Vellingiri et al. (2023) [9]	Confined-workplace extraction patterns	Collected fume and extraction geometry	Collection endpoint; abstract access
Sabzehali et al. (2023) [10]	Low-volume, high-velocity hood comparison	Near-torch metal concentrations	Not established personal exposure; abstract access
Freire de Carvalho et al. (2024) [11]	Refinery monitoring, 2008–2018	Particulate, Cr(VI) and Mn exposure	Historical contextual comparison; abstract access
Pili et al. (2024) [12]	Maintenance-shop exposure characterisation	Fine and ultrafine particle metrics	Not an isolated LEV intervention; limited text access
Park et al. (2024) [13]	Ship engine-room ventilation simulation	Predicted particle and airflow distributions	Modelled room ventilation; abstract access
Xia et al. (2026) [14]	Position-dependent laboratory monitoring	Ozone and particle peaks under LEV	Specified configuration; sensor limitations
Yamane et al. (2026) [15]	Workplace and laboratory ozone monitoring	Breathing-zone ozone and airflow context	Sensor interference; overlap with [14] unresolved

Study	Design / setting	Main endpoint or contribution	Critical-appraisal boundary
Spinazzè et al. (2026) [16]	22 welders and 10 administrative controls	Airborne and biological chromium	Observational uptake; no causal LEV estimate
Ngali and Mustaffa (2023) [17]	14 LEV hoods; UTHM welding laboratory	Face and capture velocity; duct and fan checks	Engineering measurements; no personal fume sampling
Amiruddin et al. (online 2024) [18]	Training-facility LEV; experiment and CFD	Agreement between measured and simulated airflow	Publisher-deposited abstract; no exposure effect estimate
Abdull et al. (2024) [19]	Malaysian educational workstation; GTAW	Current-dependent particle characteristics	Conference report; no LEV intervention

Engineering and Modelling Evidence, 1997-2022

Airflow fields and task-based exposure

The earliest eligible evidence in this synthesis addressed the physical conditions of capture. Kulmala modelled the airflow field near a flanged welding exhaust hood, reinforcing that centreline capture-velocity assumptions become unreliable when the source is displaced or the geometry is complex [26]. Susi et al. then demonstrated the value of task-based exposure assessment in construction. Their T-BEAM programme treated the welding or thermal-cutting task as the principal unit of exposure assessment and found that local or mechanical ventilation was associated with lower mean fume exposure [27]. The study is important methodologically because it connected engineering control to the changing task environment rather than treating job title as a sufficient exposure descriptor. Ojima et al. simulated CO₂ arc welding in a confined chamber and recorded high time-averaged fume concentration during arcing. Air-duct ventilation at 1.08–1.80 m³/min did not drastically reduce exposure during arcing, although it cleared residual contamination more rapidly after welding stopped [28]. This negative or limited result is central to interpreting confined-space work: an airflow system that improves post-task clearance is not necessarily adequate source control during emission. It also anticipates the oil-and-gas problem of welding inside tanks, modules, vessels and other enclosed equipment.

Portable hoods, push-pull systems and extraction torches

Zaidi et al. reported that portable and mobile LEV reduced breathing-zone manganese by 63% and 88%, respectively, when the hood was positioned 15-20 cm from the source, although full-shift and long-term performance were not assessed [29]. Push-pull ventilation reduced welding fume at capture velocities above 0.3 m/s, but airflow had to be balanced with shielding-gas flow to prevent weld defects [30]. Fume-exhaust guns similarly enabled extraction near a moving arc while demonstrating potential interference with shielding gas [31]. Thus, greater suction does not necessarily provide better control if weld quality or operator use is affected. Portable LEV reduced manganese and total particulate by 75% and 60% in experimental trials, but field reductions were lower at 53% and 10%, respectively [32]. This difference was associated with variable hood positioning, background contamination and other hot-work activities, although the contribution of each factor was not isolated. LEV also reduced median hexavalent chromium by 68%, while the weak-to-moderate correlation between total particulate and Cr(VI) showed that total fume is an unreliable surrogate for specific hazardous metals [33]. Subsequent studies examined integral extraction performance [34] and demonstrated effective on-gun capture without compromising weld quality, although performance during flat fillet welding remained uncertain [35]. Analysis of 2,065 particulate and 697 manganese measurements found 43% lower particulate and 67% lower manganese exposure with LEV. However, enclosed spaces increased particulate by 67% and manganese by 750%, and residual confounding remained possible [36]. A major review concluded that properly positioned and adequately powered LEV could reduce exposure by at least 40-50% [37]. On-

torch capture was influenced by induced velocity, torch angle, deposition rate and transfer mode, with a minimum calculated velocity of 0.25 m/s proposed [38]. A bench prototype achieved 77.73% capture efficiency at a 2-cm hood distance, but performance declined with increasing distance [39]. In Malaysia, a conical hood provided the best visible-fume removal in a small enclosure, although the test did not represent industrial conditions [40]. Together with Malaysian airflow and CFD studies [17,18], these findings demonstrate local engineering capability; however, the included sources did not provide prospective personal-exposure evaluations in Malaysian welding facilities.

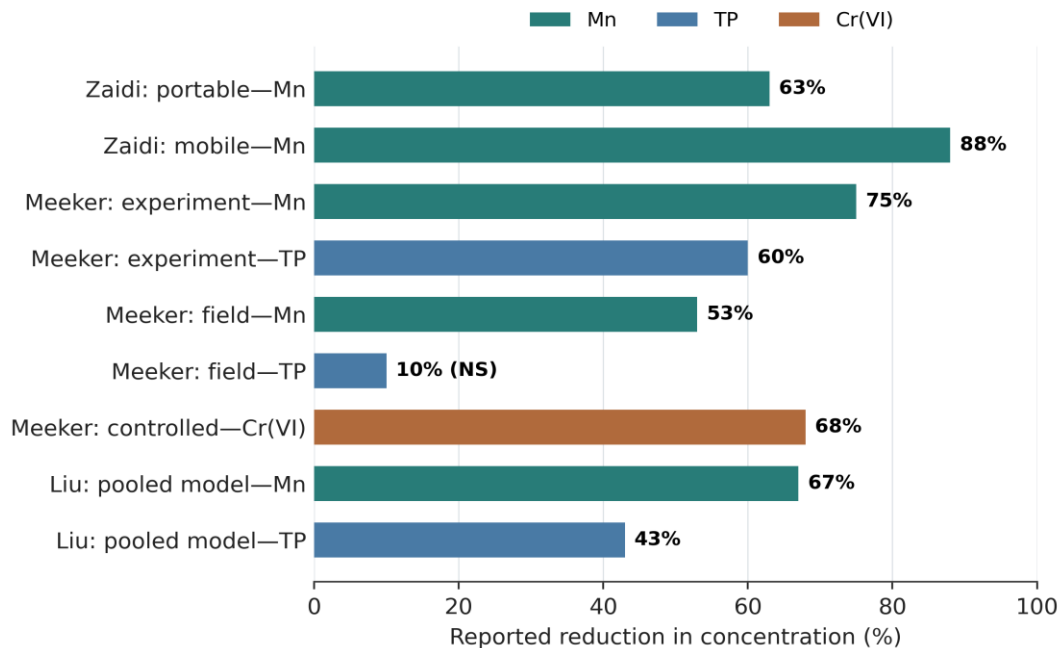


Fig. 2. Reported LEV-associated concentration reductions in selected foundational studies.

Table II. Foundational evidence connecting LEV design, capture and exposure, 1997-2022, with design-specific appraisal boundaries.

Study	Design / setting	Key finding used in this synthesis	Critical-appraisal boundary
Kulmala (1997) [26]	Numerical airflow analysis; flanged welding hood	Capture field depends on hood geometry and source position; centreline assumptions have limits.	Engineering airflow model; no personal exposure.
Susi et al. (2000) [27]	Task-based construction exposure programme	Local or mechanical ventilation associated with lower mean fume exposure; task is a useful exposure unit.	Observational programme; ventilation categories and tasks vary.
Ojima et al. (2000) [28]	Robotic CO2 welding in a confined chamber	Air-duct ventilation improved post-weld clearance but did not drastically reduce exposure during arcing.	Laboratory chamber; not a direct portable-LEV comparison.
Zaidi et al. (2004) [29]	Portable and mobile LEV trials; arc welding	Breathing-zone Mn reductions of 63% and 88% for the two evaluated units.	Trial-based means; limited replication and no full-shift follow-up.

Study	Design / setting	Key finding used in this synthesis	Critical-appraisal boundary
Iwasaki et al. (2005) [30]	Push-pull ventilation; CO2 welding	Capture velocity above 0.3 m/s reduced breathing-zone fume below cited limits; shielding-gas flow affected weld integrity.	Laboratory conditions; historical control values.
Meeker et al. (2007) [32]	Paired trials plus two-pipefitter field study	Experimental Mn and TP reductions of 75% and 60%; field Mn reduction 53%, TP reduction 10% (not significant).	Small field sample; background tasks and placement vary.
Meeker et al. (2010) [33]	Four datasets plus controlled LEV trials	Controlled LEV reduced median Cr(VI) by 68%; TP was a weak-to-moderate Cr(VI) surrogate.	Mixed datasets; controlled result is endpoint-specific.
Saunders et al. (2010) [35]	Integrated on-gun capture tests	Efficient capture without compromised weld integrity in evaluated conditions; flat fillet configuration remained uncertain.	Capture study; ergonomics and operability not assessed.
Liu et al. (2011) [36]	Mixed models; 2,065 TP and 697 Mn measurements	LEV presence associated with 43% lower TP and 67% lower Mn; enclosure strongly increased exposure.	Observational pooled data; residual confounding possible.
Flynn and Susi (2012) [37]	Literature review; construction and related industries	Field evidence suggested 40–50% or greater reductions when positioning and flow were adequate.	Prior review ending in 2010; few construction-specific studies.
Bonthoux (2016) [38]	Experimental on-torch capture study	Induced velocity, torch angle, deposition rate and transfer mode governed capture.	Capture efficiency, not breathing-zone dose.
Yarahmadi et al. (2018) [39]	Bench-scale on-gun prototype	77.73% capture efficiency at 2-cm hood distance; capture velocity fell with distance.	Prototype and engineering endpoint.
Rosli and Yasak (2021) [40]	Malaysian portable prototype in 1 m ³ enclosure	Conical hood performed better in short visible-fume and filter-collection tests.	Educational prototype; no personal contaminant sampling.

Controlled and Comparative Exposure Evidence

Engineering investigations offered useful information about how extraction arrangements intercept emissions. Egerland et al. examined technical measures across welding conditions [8]. Kuppusamy Vellingiri et al. compared extraction patterns using collected fume [9]. Sabzehali et al. evaluated low-volume, high-velocity hood arrangements, with contaminant measurements taken near the torch [10]. These endpoints help explain capture behaviour, but neither collected filter mass nor a fixed near-source concentration automatically represents the worker's breathing-zone exposure. The direction of a result must therefore be interpreted against its measurement definition.

Comparative extraction evidence

Knott et al. compared industry-used controls under experimental welding conditions [3]. Table III and Fig. 3 reproduce selected summary data for flux-cored arc welding (FCAW) and metal inert gas (MIG) welding. Both hood and on-gun extraction produced lower median total-fume and manganese concentrations than the corresponding no-LEV condition. The measurements shown were outside a powered air-purifying respirator (PAPR) helmet; all conditions involved PAPR use. Each process-control cell contained three measurements from the experimental programme, not three independent workers. These data support a configuration-specific reduction in external airborne exposure. They do not establish the concentration inhaled inside the respirator, a universal ranking across every process, or long-term performance. The reported interquartile ranges are retained as widths in Table III; quartile boundaries were unavailable for constructing defensible uncertainty bars. Industry funding and the sponsor's contribution to equipment and study design should also inform appraisal [3].

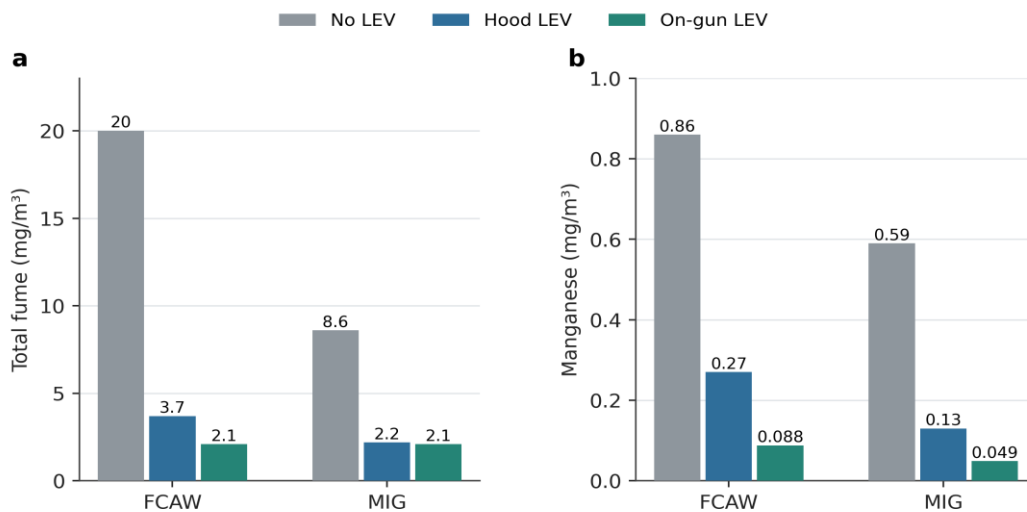


Fig. 3. Median (a) total-fume and (b) manganese concentrations for FCAW and MIG conditions, measured outside the PAPR helmet. Original visualisation of selected published summary data from Knott et al., Table 6 [3], CC BY 4.0. Each bar represents three measurements; all conditions used PAPR. Quartile boundaries were unavailable, so uncertainty bars are omitted; IQR widths appear in Table III. These are experimental external concentrations, not inhaled dose or population effect estimates.

Table III. Published median total-fume and manganese concentrations outside the PAPR helmet.

Process	Control	n	Total fume, mg/m ³ Median (IQR width)	Mn, mg/m ³ Median (IQR width)
FCAW	No LEV	3	20 (19)	0.86 (2.23)
FCAW	Hood LEV	3	3.7 (2.2)	0.27 (0.18)
FCAW	On-gun LEV	3	2.1 (1.7)	0.088 (0.077)
MIG	No LEV	3	8.6 (8.5)	0.59 (0.44)
MIG	Hood LEV	3	2.2 (3.1)	0.13 (0.153)
MIG	On-gun LEV	3	2.1 (1.6)	0.049 (0.084)

Source: selected cells from Knott et al., Table 6 [3], CC BY 4.0; reformatted here. All conditions used PAPR. These are repeated experimental measurements, not independent worker groups. IQR is reported as a width,

not lower and upper quartiles. FCAW, flux-cored arc welding; MIG, metal inert gas; other abbreviations as in Table I.

For comparative analysis, a useful descriptive quantity is the ratio of a concentration measured with LEV to the corresponding concentration without LEV, provided the endpoint and sampling protocol are comparable. A percentage contrast can then be expressed as $100 \times (1 - \text{concentration ratio})$. When applied to published medians, this is a contrast between group summaries. It is not automatically the median individual reduction, a paired treatment effect or an estimate with known precision. The unit of replication must remain explicit: repeated samples from one operator do not support the same population inference as independent observations across workers and facilities. An equipment specification describes a proposed control capability; workplace measurements test whether it is achieved. Transfer requires reassessment when process, joint geometry, posture or production changes.

EXPOSURE-CHARACTERISATION EVIDENCE

Particle mass, composition and particle number

Kóvágó et al. investigated nanoparticle removal using an extraction-equipped TIG torch [4]. Both comparison conditions also involved background ventilation arrangements, so the study concerns the additional effect of torch extraction rather than ventilation versus its complete absence. The findings extend the evidence beyond gravimetric fume mass. Pili et al. likewise characterised fine and ultrafine particles during maintenance-shop welding, showing why particle-size information can add to conventional mass measurements [12]. Neither study establishes a single conversion between particle number and inhaled metal mass.

Ozone and time-resolved measurements

Recent ozone studies broaden the assessment beyond particulate emissions. Xia et al. examined position-dependent relationships between ozone and welding-fume peaks under a specified LEV arrangement [14]. Yamane et al. combined workplace and laboratory observations, with attention to breathing-zone ozone, posture and airflow [15]. These studies support the value of spatial and temporal information and they do not validate ozone as a universal surrogate for particulate exposure. Potential sensor interference and the distinction between extraction and air movement from a blower require explicit consideration. Monitoring should therefore be designed around a defined decision. If the decision concerns a short task-related peak, instrument response and time synchronisation are essential. If the decision concerns shift exposure, monitoring must represent the relevant work period. If the decision concerns control failure, a sensor signal should be linked to a recorded task or operating event before an alarm threshold is interpreted as evidence of inadequate extraction. Calibration, cross-sensitivity and background measurements belong in the methods rather than being left implicit. The two ozone publications share investigators and related subject matter [14,15]. The independence of their underlying observations should be checked before any later quantitative synthesis.

Workplace Observational, Intervention and Biomonitoring Evidence

Workplace observational and multi-component intervention evidence

Workplace evidence adds realism while introducing confounding. The refinery study reported differences associated with task and environmental conditions, including enclosed work, and compared exposure patterns under different ventilation arrangements [11]. Its historical monitoring series should not be interpreted as longitudinal verification of one unchanged LEV system. The Australian survey and workplace investigation provide complementary information on control provision and measured exposure [1,2], but neither is a randomised comparison of extraction devices. Installation status, observed use and demonstrated effectiveness remain separate variables. Assenhøj et al. studied manual welders, robot operators and bystanders in two companies [5].

In one company, manual-welder median airborne manganese decreased from 146.6 to 13.3 $\mu\text{g}/\text{m}^3$ after preventive measures. This approximately 91% reduction belongs to the combined programme, not to LEV

alone. The study also examined extraction solutions, but the accessible record did not permit reconstruction of all intervention components or adjusted comparisons. It supports both the relevance of bystander assessment and the need for intervention-specific attribution. A shared welding bay should consequently be evaluated as an exposure environment with several worker groups. The operator nearest the arc may receive the most direct plume exposure, while another worker experiences emissions transported from multiple stations. A study restricted to the welder cannot establish protection for the whole bay. Park et al.'s ventilation simulation further illustrates that a general airflow descriptor need not predict particle distribution reliably [13]. Simulation can help identify candidate sampling positions, but a predicted concentration field should be distinguished from a measured personal exposure outcome.

Biomonitoring evidence

Spinazzè et al. combined environmental and biological chromium measurements in 22 welders and ten administrative controls [16]. Fig. 4 displays urinary chromium geometric means and 95% confidence intervals from the published table. Welders were sampled at the beginning and end of the workweek; controls were sampled once. The within-welder comparison was not statistically significant ($p = 0.874$). Although the facilities had ventilation provision, individual LEV status was not uniform. This is a biomonitoring comparison, not an estimate of ventilation effectiveness.

Urinary chromium indicates uptake within the interpretation limits of the biomarker; it does not identify clinical injury or isolate the dose of hexavalent chromium. Sampling time, background exposure, respiratory protection and other determinants must be considered before attributing a biological difference to LEV. The appropriate role of biomonitoring in a ventilation study is therefore complementary: it may reveal a discrepancy requiring investigation, while causal attribution still depends on the intervention design and the accompanying exposure measurements [16].

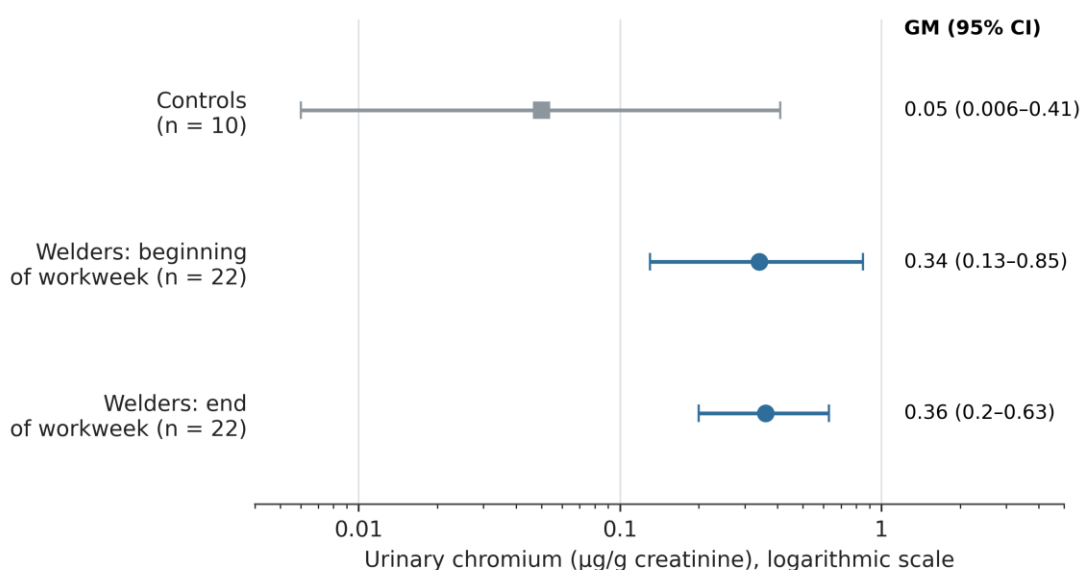


Fig. 4. Urinary chromium geometric means and 95% confidence intervals: controls ($n = 10$, sampled once) and welders ($n = 22$, sampled at the beginning and end of the workweek). Original visualisation of Spinazzè et al., Table 5 [16], CC BY 4.0. The same welders contributed both time points; the within-welder comparison had $p = 0.874$. The logarithmic axis preserves the asymmetric intervals. This comparison provides biomonitoring context and does not estimate LEV effectiveness.

ENGINEERING TRANSFER AND REGULATORY CONTEXT

Malaysian engineering and modelling evidence

Ngali and Mustaffa evaluated 14 extraction hoods in a UTHM welding laboratory [17]. All met the study's face-velocity criterion, but only four met its capture-velocity criterion at 8 inches; none met it at 16 or 24

inches. Fig. 5 summarises these counts. The investigators used 100 ft/min as their capture criterion; this is reported as a study benchmark, not a universal Malaysian statutory limit. No personal contaminant sampling was reported. The findings illustrate how a satisfactory hood-opening measurement can coexist with inadequate capture at the task location. Amiruddin et al. compared measured and simulated LEV air velocities in welding training facilities [18]. The publisher-deposited abstract reports an average absolute CFD validation error of 8.4%. This supports the feasibility of modelling the measured airflow configuration, but neither validates every welding-bay scenario nor demonstrates an equivalent reduction in inhaled fume. Full-text access was unavailable for detailed appraisal of boundary conditions and validation independence. The contrast with Ngali and Mustaffa should not be read as evidence of temporal improvement: equivalence of facilities and operating conditions was not established. Abdull et al. characterised GTAW particles in an educational workstation using 60 A and 130 A currents [19]. Reported mass concentrations were 0.064 and 0.122 mg/m³, respectively, while particle counts and morphology provided additional information. This Malaysian work supports measuring source activity and particle characteristics when interpreting control performance. It was not an LEV intervention, and these short experimental readings cannot establish full-shift compliance. Together, the three reports support a local engineering research base while leaving the connection to repeated personal exposure measurements unresolved.

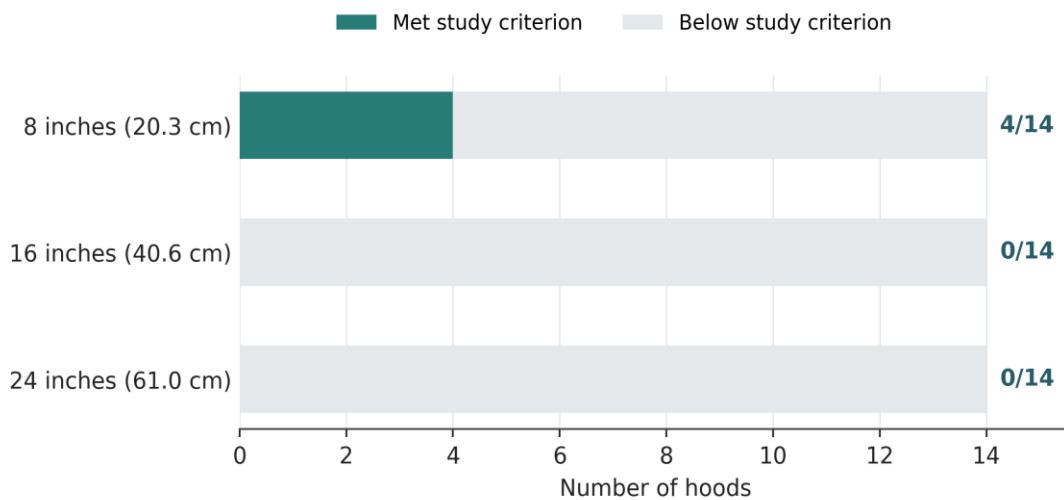


Fig. 5. Number of UTHM laboratory hoods meeting the investigators' capture-velocity criterion of 100 ft/min at three measurement distances. Original visualisation of reported counts in Ngali and Mustaffa, section 3.2 [17]. The same 14 hoods were evaluated at each distance; these are engineering results, not worker-exposure outcomes or national compliance rates.

Oil-and-gas fabrication and maintenance

The fabricated-metal supply chain supports the oil-and-gas sector [20], including welding for offshore structures, pipeline installation and maintenance habitats [21]. Assessments should distinguish fixed fabrication bays, temporary maintenance sites and confined spaces. Pipe-spool fabrication permits repeated LEV comparisons, whereas shutdown work requires documentation of changing access, geometry, enclosure and simultaneous activities. The refinery study provides relevant occupational evidence [11]. Future evaluations should combine engineering measurements with personal fume and metal sampling among welders, fitters and nearby workers. Arc-on time, materials, consumables, respiratory protection and concurrent controls must also be recorded to isolate LEV effectiveness across fabrication and maintenance conditions.

DOSH requirements and verification records

The Occupational Safety and Health Act 1994, reprinted on 1 June 2024, establishes employer duties to employees and affected non-employees under sections 15 and 17. Sections 18A and 18B address principal and contractor responsibilities, risk assessment and necessary controls [22]. Assessments should therefore

include welders, contractors and adjacent workers. The USECHH Regulations 2000 provide the chemical exposure control framework [23]. Monthly employer inspections and LEV examinations by a hygiene technician at intervals not exceeding 12 months are distinct from exposure monitoring under regulation 26. Annual LEV testing does not replace exposure monitoring, while health surveillance depends on the assessment and regulation 27.

Exposure must be interpreted using applicable Malaysian limits and averaging periods. DOSH's LEV guideline requires inspection of hoods, ducts, fans, air cleaners and operating practices against design and commissioning records [24]. These checks explain system performance but do not measure personal exposure; therefore, engineering, task and exposure records should be linked. For confined space welding, the 2010 Industry Code requires entry control, isolation, atmospheric assessment, continuous ventilation and emergency arrangements [25]. Oxygen cannot be used for ventilation, and satisfactory LEV performance alone cannot confirm that a tank or vessel is safe for entry or hot work.

Table IV. Malaysian requirements and their implications for LEV verification.

Authority / status	Selected requirement	Implication for evidence and records
OSHA 1994, ss.15, 17, 18A–18B [22] Statutory duties	Employer and affected-person protection; risk assessment and necessary controls. Principal duty under s.18A is subject to direction over the manner of work.	Define affected worker groups and contractor arrangements; document task-specific hazards and controls.
USECHH, regs.9–11, 14–16 [23] Regulations	Written chemical health risk assessment by an assessor; assessment review triggers and exposure-control duties. PPE use is subject to reg.16 conditions.	Record process, material, hazards, control rationale and assessment recommendations; distinguish LEV and respiratory protection.
USECHH, reg.17 [23] Regulation	Employer inspection at intervals ≤ 1 month; hygiene-technician examination and effectiveness testing at intervals ≤ 12 months. Maintain and operate controls as required.	Retain inspection and test findings; link defects and corrective work to subsequent exposure measurements.
USECHH, regs.18–19 [23] Regulations	LEV design to approved standards by a registered professional engineer; construction to specification and post-installation testing by that engineer. Maintain equipment records.	Preserve design and commissioning values as the engineering comparison baseline.
USECHH, regs.26–27 [23] Regulations	Assessment-dependent exposure monitoring and health surveillance. Schedule II provisions include monitoring ≤ 6 months and medical surveillance ≤ 12 months, or shorter specified intervals.	Apply the relevant conditions and competent-person requirements. LEV examination is distinct from exposure monitoring and medical surveillance.
DOSH LEV guideline, 2008 [24] Technical guidance	Inspection and examination address hood, duct, fan, air-cleaner performance and operating conditions.	Record measurement locations, operating state and comparison with design/commissioning results.
DOSH confined-space ICOP, 2010 [25] Code of practice	For qualifying spaces: entry controls, atmospheric testing, ventilation, hot-work precautions and rescue arrangements; continuous ventilation during occupancy.	Assess fume extraction within the wider entry-control system. Record oxygen and relevant gas hazards separately from particulate exposure.

Original regulatory mapping from the cited official documents, checked on 4 September 2026. The final column is the review authors' proposed research application. Selected provisions are summarised; legal scope and assessment-dependent conditions remain applicable. DOSH, Department of Occupational Safety and Health; USECHH, Use and Standards of Exposure of Chemicals Hazardous to Health; ICOP, Industry Code of Practice; PPE, personal protective equipment.

DISCUSSION

From equipment presence to demonstrated protection

The most direct evidence indicates that LEV can reduce external airborne fume and metal concentrations under defined conditions, particularly when the hood or torch is close to the source and airflow and source-hood geometry are favourable [3,26,29,32,33,38,39]. Confidence is lower for sustained workplace effects because observational comparisons are vulnerable to task differences, background emissions, enclosure and concurrent controls [1,2,11,36]. Field effects may be weaker than controlled results [32], confined-space ventilation may improve clearance without adequately controlling exposure during arcing [28], and ventilation may be absent, inactive or inconsistently used in some workplaces [1,2]. The evidence therefore supports a conditional conclusion: LEV is a potentially effective source control, but its protection cannot be inferred from equipment presence or a single engineering measurement. Effectiveness should be verified through matched capture, personal-exposure and adjacent-worker measurements, as outlined in Figure 1 and Table V. Controlled experiments can isolate design factors, whereas workplace studies must represent operational variability. The included Malaysian sources cover prototypes, hood-distance testing, CFD and particle characterisation [17-19,40], but do not establish national LEV performance or oil-and-gas worker exposure.

Research gaps and testable questions

The evidence map identifies several recurring gaps. Few sources linked LEV capture performance directly with breathing-zone exposure during the same welding task. Changing posture, hood position, workpiece geometry and competing airflow were incompletely represented. In the mapped workplace evidence, LEV effects were seldom isolated from concurrent interventions such as training, housekeeping and respiratory protection. Evidence on sustained performance across complete maintenance cycles and protection of nearby workers in shared welding bays was also limited. Measurement inconsistency restricted comparison because total particulate is not a reliable surrogate for Cr(VI) [33], while capture efficiency cannot be equated directly with personal-exposure reduction [38,39]. These are gaps within the 32 mapped primary sources, not proof that no relevant study exists outside the searched sources.

Table V. Proposed verification domains and research priorities for welding-bay LEV.

Verification domain	Minimum evidence to report	Unresolved question / next study	Informing sources
Capture exposure to	Matched source and personal measurements; source-hood-worker geometry	When does capture predict breathing-zone reduction? Compare both endpoints during the same task.	[3,4,8-10]
Operational robustness	Process, material, posture, arc-on time, cross-drafts and observed use	How stable is performance across realistic task changes? Use repeated crossover comparisons.	[2-4,14,15]
Intervention attribution	Control changes, concurrent measures, baseline comparability	Which effect belongs to LEV? Use staged implementation or suitable comparison groups.	[5,8,11]

Verification domain	Minimum evidence to report	Unresolved question / next study	Informing sources
Sustained performance	Repeated exposure and airflow measurements; maintenance history	Does performance persist over maintenance cycles? Link changes in exposure to operating condition.	[2–5,11]
Shared-bay protection	Personal and area measurements across relevant worker groups	Does source control protect adjacent personnel? Evaluate simultaneous sources and spatial redistribution.	[2,5,13]
Endpoint comparability	Sample fraction, analyte, sampler position, averaging time, calibration and uncertainty	Which complementary metrics explain residual exposure? Align particle, gas and biological measurements.	[3,4,12,14–16]
Malaysian oil-and-gas transfer	Linked engineering and personal exposure records across fabrication and maintenance	Do routine LEV indicators predict exposure across task changes and maintenance cycles?	[11,17–25]

LIMITATIONS OF THE PRESENT REVIEW

This scoping review has important methodological limitations. Although the question, eligibility criteria, information sources, concept blocks, charting fields and evidence strata are now reported, the original searches were iterative and complete record-level exports were not retained. Screening counts, duplicate-removal counts and exclusion reasons therefore could not be reconstructed reliably, so a PRISMA-ScR flow diagram is not presented and full PRISMA-ScR compliance is not claimed. Scopus and Web of Science were not searched systematically; studies indexed only in subscription databases, non-English publications or grey literature may have been missed, and selection bias cannot be excluded. No protocol was registered prospectively, and independent duplicate screening was not documented. Abstract-only access limited assessment of some sources. The design-specific appraisal boundaries aid interpretation but are not validated risk-of-bias instruments, and no certainty grading was applied. Heterogeneity across experiments, workplace observations, simulations and biomonitoring prevents the map from providing a single quantitative estimate of LEV effectiveness. Repeated samples may not be independent, control definitions differ, and respiratory protection complicates comparisons between ambient exposure and inhaled dose. Accordingly, the review maps evidence patterns and generates conditional conclusions; it does not establish exhaustive coverage or a definitive causal effect.

CONCLUSION

This scoping review mapped 32 primary sources spanning engineering capture, controlled exposure comparisons, workplace evidence, modelling, particle and gas characterisation and biomonitoring. Across the mapped literature, LEV was associated with lower welding-fume exposure when extraction airflow, hood or torch position, welding orientation and operator work practices were appropriately controlled. Evidence was strongest for defined experimental configurations and less consistent for sustained workplace performance. Equipment presence or satisfactory capture performance alone did not demonstrate continued exposure reduction. Performance was sensitive to enclosed spaces, background contamination, competing airflow, changing geometry, task variation, hood positioning and use. The evidence map therefore supports complementary engineering and occupational-exposure measurements: airflow, capture velocity and hood geometry characterise system operation, while repeated personal breathing-zone sampling tests whether external exposure is reduced during representative work. Respiratory protection must be documented so ambient concentration is not confused with inhaled dose. Bystanders and adjacent workers require inclusion

because emissions may disperse beyond the controlled workstation. Longitudinal evaluation across inspection, maintenance and filter-loading cycles remains sparsely represented. Linking LEV measurements with personal exposure, task information, respiratory protection and enclosure conditions would better determine whether installed systems deliver sustained protection in realistic welding bays.

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