DOES OUR BSL-3 HAVE TOO MUCH LEAKAGE?

Diagnostic Guide
GD-012

A technical diagnostic guide to envelope leakage, pressure control, airflow demand, and leak tightness in containment laboratories

A practical guide to distinguishing acceptable transfer leakage from uncontrolled envelope leakage and understanding how leakage changes airflow, energy, stability, and containment performance.

DIAGNOSTIC GUIDE

HOW TO USE THIS GUIDE

NEGATIVE PRESSURE DOES NOT TELL YOU HOW LEAKY THE ROOM IS.

This guide was created for laboratories that maintain a negative-pressure reading but require more exhaust than expected, recover poorly after door openings, consume increasing amounts of energy, or show evidence that the envelope has changed over time.

Why we developed it

A negative-pressure room is expected to receive air through defined transfer paths and unavoidable leakage. The engineering problem begins when leakage becomes excessive, poorly located, variable, or incompatible with another required function such as gaseous decontamination.

Because exhaust can compensate for leakage, the pressure monitor may continue to display an acceptable value while the fan works harder, control margin decreases, and a deficient envelope condition remains hidden behind the performance of the mechanical system.

The purpose of this guide is to help technical teams determine whether airflow demand reflects the intended containment strategy or whether the mechanical system is compensating for an envelope problem.

Who can use it

The guide is intended for architects, HVAC engineers, commissioning teams, facility managers, biosafety personnel, maintenance personnel, and institutional authorities responsible for BSL-3 or other high-containment facilities.

It may be used during design review, commissioning, periodic verification, troubleshooting, renovation, or retrospective assessment of an operating facility.

HOW TO USE IT IN PRACTICE

Begin by identifying the intended transfer-air paths and the accepted pressure condition. Compare supply, exhaust, and the current fan operating point with the baseline. Inspect and test the envelope where appropriate, distinguish intentional transfer from uncontrolled leakage, and determine what cost that leakage imposes on the system in airflow, stability, and capacity.

The objective is not to make every BSL-3 perfectly airtight. It is to understand and control where air crosses the envelope, how much airflow that condition requires, and whether the envelope remains suitable for its intended containment functions.

01 BASELINE

02 LOCATE

03 QUANTIFY

04 CORRECT

HOW THIS GUIDE MAY BE USED — AND WHAT IT DOES NOT AUTHORIZE

This guide is a general diagnostic-orientation tool. It is designed to help structure technical questions, organize evidence, and define what requires more specific evaluation.

Acceptable use

It may be used to:

- structure preliminary technical investigations;
- prepare internal reviews and multidisciplinary discussions;
- identify missing information, measurements, and documentation;
- support definition of the scope of a subsequent evaluation;
- serve as educational and internal technical reference material.

It does not constitute

This guide does not establish a universal leak-tightness requirement and does not constitute a site-specific test protocol, acceptance criterion, certification, compliance determination, authorization to operate, or site-specific recommendation.

Technical and operational decisions

No decision regarding acceptance of leakage, envelope repair, modification of airflow values, changes to pressure criteria, continued operation, or return to service should be based solely on this guide.

Applicable technical basis

The content should be interpreted together with the risk assessment, Basis of Design, specific leak-tightness and decontamination criteria, commissioning baseline, construction drawings and details, regulatory requirements, and other site-specific documentation.

Competent personnel

Leakage and leak-tightness testing, interpretation of results, and repairs affecting the containment boundary should be performed or reviewed by appropriately qualified personnel using methods appropriate to the function of the boundary.

Responsibility

BioLab Solutions assumes no responsibility for decisions, modifications, interventions, or actions carried out outside a site-specific evaluation and without review by competent personnel.

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01 Start with the intended airflow path

Some air crossing the boundary is intentional. Some is not.

A negative-pressure containment room needs replacement air. The diagnostic question is whether that air enters through controlled paths or through an uncontrolled collection of leaks.

Intentional transfer may include

- a door undercut or defined transfer grille;
- controlled air transfer from an anteroom;
- designed leakage through door seals where appropriate;
- a specified transfer device or pressure-relief path.

Uncontrolled leakage may include

- unsealed penetrations;
- openings at the head of wall;
- poor door/frame seals;
- perimeter openings around equipment;
- abandoned services;
- access panels;
- cracked sealants or finishes.

Envelope question: if the room requires 500 CFM of transfer air, can the project explain where those 500 CFM are intended to enter?

02 Compare current airflow demand with the accepted baseline

Leakage often becomes visible indirectly through greater mechanical effort.

A room may maintain the same pressure while requiring progressively more exhaust.

Supply airflow

Compare current supply with commissioning values or previously verified values.

Exhaust airflow

Determine whether more exhaust is now required to maintain the same room pressure.

Fan speed

Review the trend in VFD position or fan speed against pressure performance over time.

Damper position

Look for exhaust dampers that have progressively moved toward fully open.

Filter resistance

Separate increased airflow demand from increased system resistance caused by filter loading.

Pressure recovery

Compare current recovery after door opening with previous or accepted performance.

> **THE SAME PRESSURE READING MAY REQUIRE VERY DIFFERENT SYSTEM EFFORT YEARS LATER.**

03 Recognize indications of excessive leakage

The room may reveal its envelope condition through several operating symptoms.

Observed symptom	Possible leakage-related interpretation
Exhaust fan near maximum speed	The fan may be compensating for greater transfer or leakage demand than intended.
Room pressure unstable after door use	A large or variable leakage area may reduce control predictability.
High inward velocity at a crack or opening	Transfer airflow may be concentrated through an unintended path.
Adjacent spaces difficult to balance	Uncontrolled leakage may couple zones that were intended to behave more independently.
Increasing energy consumption	More conditioned replacement air may be moving through the room to maintain pressure.
Difficulty with gaseous decontamination	Envelope leakage may exceed what the treatment strategy can tolerate.
Correct pressure but little fan margin	Containment is being maintained with reduced resilience rather than restored envelope performance.

No single symptom demonstrates excessive leakage. The pattern becomes convincing when airflow, fan position, envelope inspection, and trend history point in the same direction.

04 Locate the leakage before attempting to “seal the room”

Not every opening should be closed indiscriminately.

The repair strategy should distinguish required transfer paths from defects.

Walk the envelope

- door perimeter and threshold;
- wall-to-floor joints;
- wall-to-ceiling/slab interfaces;
- electrical penetrations;
- pipe and duct sleeves;
- pass-throughs and autoclaves;
- access panels;
- abandoned penetrations.

Preserve intended transfer

If the room depends on a defined transfer path, sealing it without rebalancing may alter the pressure relationship, increase door-opening force, or shift airflow to another path.

Repair uncontrolled leakage first, then restore the intended airflow balance.

SEAL THE DEFECTS — NOT THE AIRFLOW STRATEGY.

05 Understand how door leakage differs from random leakage

Leak location matters as much as quantity.

Door-associated transfer may be useful when

- air is intended to move from a cleaner space toward a higher-containment space;
- the path is predictable;
- door operation does not destabilize the cascade;
- air velocity is reasonable;
- the design basis explicitly depends on it.

Random leakage is harder to control

Leakage through ceiling joints, service penetrations, or concealed cavities may draw air from spaces that were not intended to form part of the containment cascade.

This can complicate pressure balance, decontamination, energy use, and interpretation of directional airflow.

CONTROLLED LEAKAGE IS PART OF THE AIR PATH. RANDOM LEAKAGE IS AN ENVELOPE CONDITION.

06 Determine whether leakage is consuming fan authority

Leakage can consume the mechanical margin needed for disturbances, filter loading, and future changes.

The system may continue meeting today's pressure setpoint while losing its ability to tolerate tomorrow's disturbance.

Fan reserve

How much speed or static-pressure capability remains above the current operating point?

Filter loading

Will expected HEPA loading consume the remaining fan margin?

Door event

Can the system recover from an ordinary door opening without reaching control limits?

Standby operation

Can redundant equipment handle the same leakage demand during failure of the duty fan?

Future equipment

Does capacity remain for legitimate additional exhaust or thermal load?

Seasonal effects

Do building pressure or wind exposure alter leakage behavior and available control margin?

> A room that requires maximum exhaust to maintain its normal differential has little resilience even if the pressure monitor still indicates the correct value.

EVERY UNCONTROLLED CFM HAS A LIFECYCLE COST

Leakage affects more than containment. It also increases the volume of air that the facility must move, condition, filter, and exhaust.

Fan energy

Additional exhaust airflow and higher static-pressure requirements increase electrical demand.

Cooling load

Additional replacement air must be cooled when outside air or warmer air from adjacent zones enters the controlled area.

Heating / reheat

Conditioning large volumes of air can increase heating and reheat energy in cold climates or tightly controlled environments.

Filter loading

A greater volume of processed air may increase the total particle load on filters and contribute to increasing resistance over time, depending on air and system conditions.

Equipment wear

Fans and actuators operating continuously at high demand have less operating margin and may experience greater mechanical stress.

Future capacity

Airflow used to compensate for leakage is capacity no longer available for legitimate process or facility needs.

AN ENVELOPE DEFECT CAN BECOME A PERMANENT MECHANICAL LOAD.

07 Use leak-tightness testing for the right question

A leakage test can quantify envelope performance, but its meaning depends on the test basis.

Define before testing

- the boundary to be tested;
- temporary closures;
- test pressure;
- method;
- acceptance criterion;
- instrumentation;
- treatment of intentional openings.

Possible methods

Depending on the project, pressure-decay, constant-flow, or other leakage-testing approaches may be used.

The method should be selected because it answers the facility's containment question, not simply because it is available.

Important: a whole-room leakage result does not identify every defect location. Local smoke, tracer, or other investigative methods may be required to locate repair points.

08 Separate pressure control from leak tightness required for decontamination

The envelope may need to perform differently during normal operation and during gaseous treatment.

A room may be sufficiently negative for routine operation and still be too permeable for a planned decontamination cycle.

Operational pressure control asks

- does air move in the intended direction?
- is the pressure relationship stable?
- can the HVAC system maintain it with reasonable margin?
- does the room recover acceptably after disturbances?

Decontamination raises additional questions

- can the room retain the agent concentration?
- could the agent escape into uncontrolled spaces?
- are seals/materials compatible?
- can ducts and penetrations be adequately isolated?

A ROOM MAY BE TIGHT ENOUGH FOR PRESSURE CONTROL AND NOT TIGHT ENOUGH FOR DECONTAMINATION.

COMMON LEAKAGE MISDIAGNOSES

WHAT SHOULD NOT BE CONCLUDED TOO QUICKLY

“It is negative, so the envelope is fine.”

The exhaust system may simply be compensating for a deficient envelope.

“More exhaust will solve it.”

More exhaust may recover pressure while increasing energy consumption and reducing fan margin.

“All leakage is unacceptable.”

Negative-pressure rooms need replacement air; the issue is whether transfer paths are deliberate and controlled.

“Seal everything.”

Closing intended transfer paths without rebalancing may create door-force, airflow, and pressure problems.

“The leakage test failed, so the room cannot operate.”

The consequence depends on the criterion that failed, the function that criterion supports, and the basis accepted by the institution.

“The same test result means the same thing everywhere.”

Leakage criteria are facility-specific and should be interpreted against the intended containment function.

LEAKAGE MUST BE INTERPRETED — NOT SIMPLY OBSERVED.

REPAIR STRATEGY

CORRECT THE ENVELOPE, THEN REBALANCE THE SYSTEM

Envelope repair changes the airflow path. The HVAC system should therefore be reevaluated after a significant leakage correction.

01

Prioritize the defects.
Address direct uncontrolled leakage, large openings, unstable interfaces, and defects that affect decontamination or pressure stability.

02

Repair with compatible details.
Use appropriate substrate preparation, sealant/gasket systems, and solutions compatible with movement.

03

Verify the repaired envelope.
Inspect and retest as appropriate to the significance of the repair.

04

Remeasure airflow.
Supply and exhaust values may require adjustment because the transfer-air requirement has changed.

05

Retune the controls.
Pressure-control loops may require adjustment if the room now responds differently.

06

Verify disturbance response.
Confirm pressure stability, directional airflow, and recovery under normal operating conditions.

> Successful envelope repair may reduce airflow demand. If the system is not rebalanced afterward, the room may become excessively negative or door operation may become difficult.

LEAKAGE SHOULD BE MEASURED WITH A METHOD THAT ANSWERS THE QUESTION BEING ASKED

Method / evidence	What it may indicate
Operational airflow balance	How much supply and exhaust airflow move under the measured condition; it may suggest the magnitude of replacement air but does not locate every leakage path.
Smoke / airflow visualization	Where air enters or leaves at accessible interfaces and whether airflow direction matches the intended path.
Targeted local measurements	Velocity or flow behavior at transfer openings, door gaps, or other defined paths.
Room pressurization / decay test	Envelope leakage under a defined test pressure and configuration when that type of test forms part of the facility criteria.
Trend comparison	Whether increasing airflow demand, fan speed, or recovery time suggests that the envelope or system resistance has changed over time.

> No measurement should be interpreted beyond its test condition. Operating pressure, airflow offset, and formal leak-tightness testing answer related but different questions.

AFTER SEALING WORK

CLOSING LEAKS CHANGES THE AIR SYSTEM — REVERIFY THE NEW CONDITION

Envelope repair may improve performance, but it also changes the airflow path and pressure response that the HVAC system previously controlled.

Rebalance

Confirm supply and exhaust airflow and reestablish the intended relationships between rooms.

Check directional airflow

Verify that intended transfer paths still carry air in the required direction after leakage is reduced.

Review door behavior

Confirm that door force, closing, interlock behavior, and recovery remain acceptable.

Review control authority

Confirm that the system is not overcorrecting or oscillating because the previous offset is no longer appropriate.

Recheck alarms

Verify that pressure thresholds and delays remain appropriate for the accepted operating condition after repair.

Update the baseline

Record repaired locations, test results, and the new accepted airflow/pressure condition.

> **A SUCCESSFUL REPAIR IS NOT COMPLETE UNTIL THE HVAC SYSTEM HAS BEEN RECONCILED WITH THE REPAIRED ENVELOPE.**

DIAGNOSTIC SEQUENCE

DOES THIS BSL-3 HAVE TOO MUCH LEAKAGE?

01

Is the intended transfer-air path understood?

No → define where replacement air should enter before treating all leakage as a defect.
Yes → continue.

02

Does current airflow demand differ materially from the accepted baseline?

Yes → determine whether leakage, filter resistance, or other system changes explain the increase.
No → continue.

03

Are uncontrolled leakage paths visible or suspected?

Yes → inspect and locate envelope defects.
No or uncertain → use targeted testing where justified.

04

Is leakage consuming fan authority or destabilizing the cascade?

Yes → prioritize correction rather than normalizing the higher airflow demand.
No → continue.

05

Must the envelope support gaseous decontamination or another more demanding leak-tightness condition?

Yes → evaluate it against that independent performance requirement.
No → continue.

06

After repair, has the HVAC system been rebalanced and functionally reverified?

No → the new envelope condition has not yet been fully reconciled.
Yes → document the restored baseline.

WHAT SHOULD BE AVAILABLE?

Boundary definition

- drawings/sections;
- intended transfer paths;
- door details;
- penetration details;
- decontamination boundary;
- acceptance criteria.

Mechanical baseline

- supply/exhaust CFM;
- room pressure;
- fan speed;
- damper position;
- filter DP;
- door-recovery performance.

Envelope evidence

- visual inspection;
- leakage locations;
- leak-tightness testing;
- local leakage testing;
- repair records;
- retest results.

Lifecycle history

- new penetrations;
- door repairs;
- equipment additions;
- sealant failures;
- maintenance interventions;
- trend history.

Review objective: determine whether current leakage is intentional, acceptable, and sustainable, or whether the HVAC system is compensating for envelope degradation.

WHAT IF WE DO NOT HAVE AN ORIGINAL LEAKAGE TEST?

An operating laboratory can still establish a useful baseline of its current condition even if no commissioning leak-tightness result exists.

Reconstruct from available evidence

- original airflow schedules;
- historical TAB reports;
- fan-speed trends;
- pressure trends;
- maintenance records;
- door and seal repairs;
- modification history.

Establish a current reference

Perform a structured envelope walkdown, measure supply/exhaust and the current fan operating point, identify major leakage paths, and test the envelope where the consequence justifies it.

The objective is to create a defensible current baseline against which future drift can be detected.

WHEN THE ORIGINAL BASELINE IS MISSING, BUILD A CREDIBLE ONE BEFORE ACCEPTING CONTINUING DRIFT AS NORMAL.

IS THE HVAC SYSTEM CONTROLLING THE ENVELOPE — OR COMPENSATING FOR IT?

Use this checklist as a diagnostic-support tool. A checked item does not constitute acceptance; each element must be interpreted against the risk basis, facility configuration, and applicable criteria.

□ Identify the intended transfer-air paths and accepted room pressure / airflow condition.

□ Compare current supply, exhaust, and pressure relationship with the accepted baseline.

□ Review fan speed, damper position, and available control margin to determine whether greater mechanical effort is being used to maintain the same condition.

□ Walk doors, frames, penetrations, ceiling interfaces, service connections, and later modifications for uncontrolled leakage paths.

□ Distinguish intended transfer air and unavoidable leakage from avoidable or poorly located leakage.

□ Use the verification method appropriate to the question: airflow balance, visualization, targeted local measurement, or formal envelope testing where applicable.

□ Do not infer acceptable leak tightness solely from a negative-pressure reading.

□ Determine whether leakage affects disturbance recovery, energy consumption, gaseous decontamination, or available exhaust capacity.

□ After sealing, rebalance and reverify the room because reducing leakage changes the airflow condition that the HVAC system must control.

□ Update the accepted baseline and envelope record once the corrected configuration has been demonstrated.

> **Technical-use note:** This review checklist is a diagnostic-support tool. It does not establish site-specific acceptance criteria, replace risk assessment or professional judgment, constitute certification, or authorize operation or return to service.

If the review identifies a condition requiring site-specific evaluation, BioLab Solutions can support technical assessment, verification, and definition of the required evidence.

RELATED BIOLAB RESOURCES

EXPLORE ENVELOPES, AIRFLOW, LEAK TIGHTNESS, AND LIFECYCLE DRIFT IN GREATER DEPTH

NT-005–006
Containment closure and boundaries as design objects

NT-007–009
Penetrations, doors, and controlled interfaces

NT-010–015
Directional airflow, pressure, ACH, failure modes, and exhaust authority

NT-021–024
Verification of envelope continuity and leak tightness

NT-033
Functional testing versus compliance testing

NT-037
Maintenance as a containment-risk domain

NT-039
Lifecycle drift in containment systems

NT-045–048
Sustainability and lifecycle energy implications

BIOLAB DIAGNOSTIC GUIDES

Short technical resources organized around real containment problems rather than individual disciplines.

Series concept: symptom → system → evidence → restoration.

CLOSING DIAGNOSTIC PRINCIPLE

THE QUESTION IS NOT WHETHER THE ROOM LEAKS. THE QUESTION IS WHETHER ITS LEAKAGE IS CONTROLLED.

Every negative-pressure containment room depends on air crossing its boundary. The engineering distinction is between intended transfer and uncontrolled leakage.

When leakage becomes excessive or poorly located, the HVAC system may conceal the problem by moving more air. Pressure may still appear correct while energy demand rises, fan margin disappears, disturbance recovery worsens, and decontamination becomes more difficult.

A credible containment envelope does not have to be perfectly airtight. It should behave predictably, support the intended pressure strategy, remain compatible with other required functions, and avoid forcing the mechanical system to compensate indefinitely for preventable defects.

BIOLAB SOLUTIONS

Independent technical support for planning, design, commissioning, assessment, and lifecycle management of high-containment laboratories.

For site-specific evaluation, BioLab Solutions can support technical review, verification, and definition of evidence requirements.

LEAKAGE → AIRFLOW DEMAND → PRESSURE STABILITY → ENVELOPE PERFORMANCE