PRESSURE DIAGNOSTIC TECHNIQUES

Affordable Comfort 1994

Overview of House as a System Issues/Diagnostic Procedures

Issues	Procedures	Comment
Fuel Consumption History - Is This a High User?	- Analyze fuel bills/compare to similar housing stock & predicted use. - Separate heating, cooling and base use.	- Do high fuel bill indicate large potential for saving $? - Do savings potential justify treatment?
Is This House Treatable? - Is There an Existing Health and Safety Problem? - IAQ - Moisture - Combustion Safety - Structural/Electrical - Other - Are There Other Constraints? - What is the Improvement Budget? - Is This House Appropriate For Program? - What Does the Client Want Done? - Do Potential Savings Justify Treatment?	- Measure ambient and kitchen CO levels. - Talk w/ client about house performance, comfort and health complaints. - Visual inspection for moisture damage, wet basement, mold, odors. - Visual inspection for combustion safety problems including gas leaks, flame rollout, and deteriorated flues. - Conduct combustion safety tests for CO, draft, spillage and HX. - Visual inspection for structural/electrical problems.	- Use eyes, nose and client to find existing H. & S. problems. - Provide immediate remedial action for life threatening situations. - Don't treat house until existing H. & S. problems have been remedied. - All combustion safety problems should be inspected/repaired by heating contractor. - Think about how potential treatments may aggrevate problems or create new ones. - Can this house be fixed, or should it be left alone?
Define Thermal Boundary of House - Are There Complicated Building Details? - Where is the Current Thermal Boundary? - Is the Thermal Boundary Adequate? - How Do Construction Details Affect Boundary Location?	- Perform outside inspection of "key junctures". - Examine accessible attic, wall and crawl spaces to determine thermal boundary.	- Identified construction detail will help us determine potential for improvement and likely problems we will encounter.
Define Pressure Boundary of House - What is Overall House Airtightness Level? - Where is the Current Pressure Boundary, and Where is the Shell Leaking? - Are Intersticial Cavities Connected to Outside? - Examine Pressures at Key Junctures - Estimate Leakage to House Zones - Attic - Basement - Garage/Porch - Duct System	- Conduct Blower Door CFM50 test. - Conduct Advanced Pressure Diagnostics (APD). (with House Depress by 50 Pa, measure): *intersticial cavity pressures* *house to attic pressure* *house to basement pressure* *house to garage/porch pressure* *house to duct pressure (pressure pan)*	- Overall tightness level provides indication of gross airsealing potential. - APD allows us to disaggregate total air leakage to house zones and determine need for further tests. - APD helps us quickly prioritize which zones and key junctures to airseal.

Test Efficiency of HVAC Equipment and Distribution System - Quantify Duct Leakage - Is There Adequate Air Flow Through System? - Are HVAC Controls Set and Operating Efficiently? - Is the Distribution System Balanced?	- Conduct duct leakage test with Blower Door or Duct Blaster. - Measure temp. change over HX/coil. - Measure AC charge. - Examine controls and observe operation. - Conduct MAD-AIR pressure tests.	- Duct leakage test provides indication of gross duct sealing potential. - Proper air flow, charge and control operation is key to HVAC efficiency. - MAD-AIR pressure balancing tests help us quickly determine if imbalanced forced air distribution system is contributing to house air leakage.
After Repairs Have Been Made, Are We Leaving a Problem House? - Is There a Need For Ventilation? - House Airtightness/Sources of Moisture - Retrofit Ventilation System Guide - Are We Sure Combustion Appliances Are Safe? - Is House/Combustion Zones Depressurized? - Do Appliances Operate Under "Worst-Case"? - Are There Fireplaces ?	- Conduct Post Blower Door CFM50 test. - Calculate Build. Airtightness Guide. - Review moisture/IAQ source list. - Measure "worst-case" depressurization in all combustion appliance zones.	- Is estimated natural ventilation (from Blower Door test) adequate for existing moisture sources? - Install necessary mechanical ventilation. - Provide pressure relief and/or downsize exhaust fans to eliminate pressure induced spillage problems. - Install sealed combustion appliances if all other combustion safety remedies fail.

Blower Door:

The Blower Door measures total house air leakage to the outside through all openings and pathways at once. By itself, the blower door does not tell us which leaks are the most important. The most important leaks have the largest driving forces operating on them, or are the leaks which are connected to strong moisture or indoor air pollutant sources. Therefore, a blower door airtightness test tells us more about the relative size of holes in a house, than it does the actual natural air exchange rate of the house. Despite this limitation, annual average natural infiltration rates can be reasonably estimated from blower door airtightness test results.

Differential Pressure Gauge:

The differential pressure gauge can be used to measure the driving forces and pressures across structural boundaries. When used with a house in its normal operating condition, the differential pressure gauge can quantify the relative size of mechanical system driving forces the house normally experiences (e.g. house pressures created by duct leaks and imbalanced distribution flows). When used with a blower door, the gauge helps us determine where the existing air barrier for the house is located. By knowing the air barrier location, we can prioritize which leaks are most important, and which leaks, if sealed, will result in the largest blower door reduction.

Pressure Pan:

The pressure pan is a duct leakage diagnostic tool which is used along with a blower door to identify the relative leakiness of duct runs in a house. This technique involves placing a pressure pan over each register and taking a quick pressure reading while the blower door is depressurizing the house. This simple pressure measurement provides a quick and reliable indication of whether significant duct leaks are located near the register being tested. In addition, it can be used to tell crews if they have done a good job of duct sealing.

The Blower Door By Itself Doesn't Tell Us Enough

A Blower Door Test Does Tells Us:

- The total leakage rate (or leakage area) of the house.
- The gross potential for air tightening.
- The gross potential for duct sealing.
- A rough estimate of the natural infiltration rate of the house.

It Does Not Tell Us:

- The location of the pressure boundary. Is it the attic/house interface, or the attic/roof interface? Which leaks are most important?
- Are the pressure boundary and the thermal boundary misaligned? Are convective loops occurring between misaligned boundaries creating large heat loss potential.
- The degree to which leaks are interconnected. Are attics or crawl spaces connected to interior walls, or to the duct system?

ADVANCED PRESSURE DIAGNOSTICS

FINDING IMPORTANT AIR LEAKAGE SITES WITH SIMPLE PRESSURE MEASUREMENTS

- Many important air leaks in a house are not directly leaks to the outside. The leaks often follow complicated paths through two or more surfaces between inside and outside. Attic bypasses are a good example. These types of leaks are called "series" leaks.

- Use of simple pressure measurements can tell us how much leakage exists between the house and the attic, or the house and any other zone connected to the house (e.g. garage). This allows us to quickly prioritize airsealing treatments.

- We can also estimate how much reduction in blower door CFM50 readings can be achieved by sealing leaks in a particular part of the house. This can help prevent crews from chasing leaks from one part of the house to another.

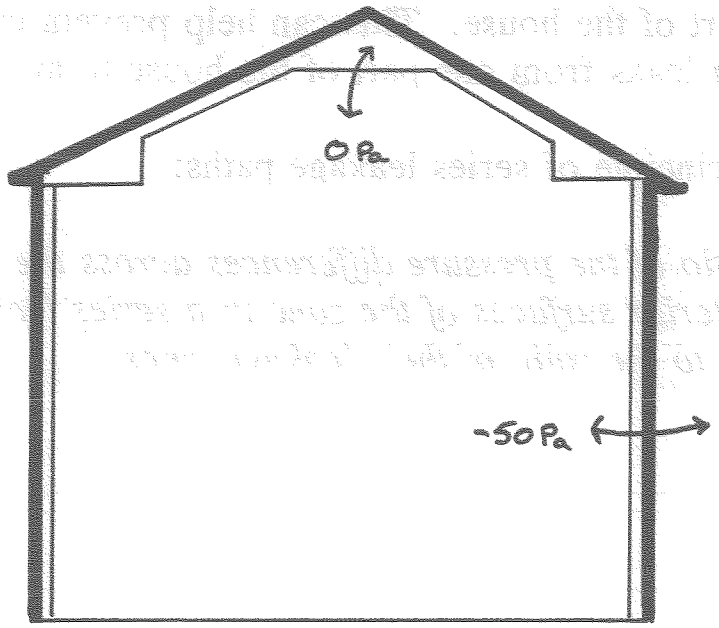
- The Basic Principle of series leakage paths:

  The ratio of the pressure differences across the interior and exterior surfaces of the zone in a series leak is related to the ratio of their leakage rates.

Consider these examples:

A house has large attic bypasses, but has a very tight roof with no attic venting. The pressure boundary measured by the blower door will be the roof/attic interface, not the house/attic interface. We know this by measuring close to 0 Pa house to attic pressure with the house depressurized by 50 Pa. What are the implications?

- Sealing attic bypasses in this house will produce no reduction in blower door CFM50.
- Adding roof vents without properly sealing attic bypasses will actually increase house CFM50.

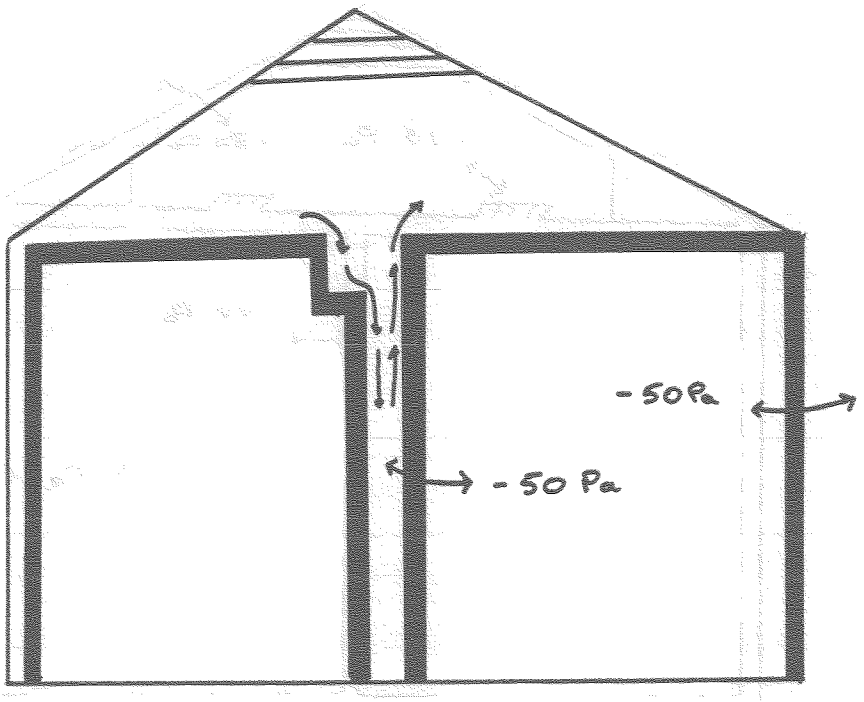


Pressure Boundary is Roof and Outside Walls

Air sealing was performed on a house using the old technique of sealing all baseboards (interior and exterior), wall outlets and other wall/ceiling joints. Some interior wall bypasses were left unsealed. The pressure boundary measured by the blower door will be the interior walls and ceilings (50 Pa pressure was measured between room and an interior wall cavity with house depressurized by 50 Pa). What are the implications?

- Sealing the open wall cavities in the attic will produce no CFM50 reduction.
- Convective looping in the interior wall cavity could create significant heat loss.

Pressure Boundary is Inside Walls and Ceiling



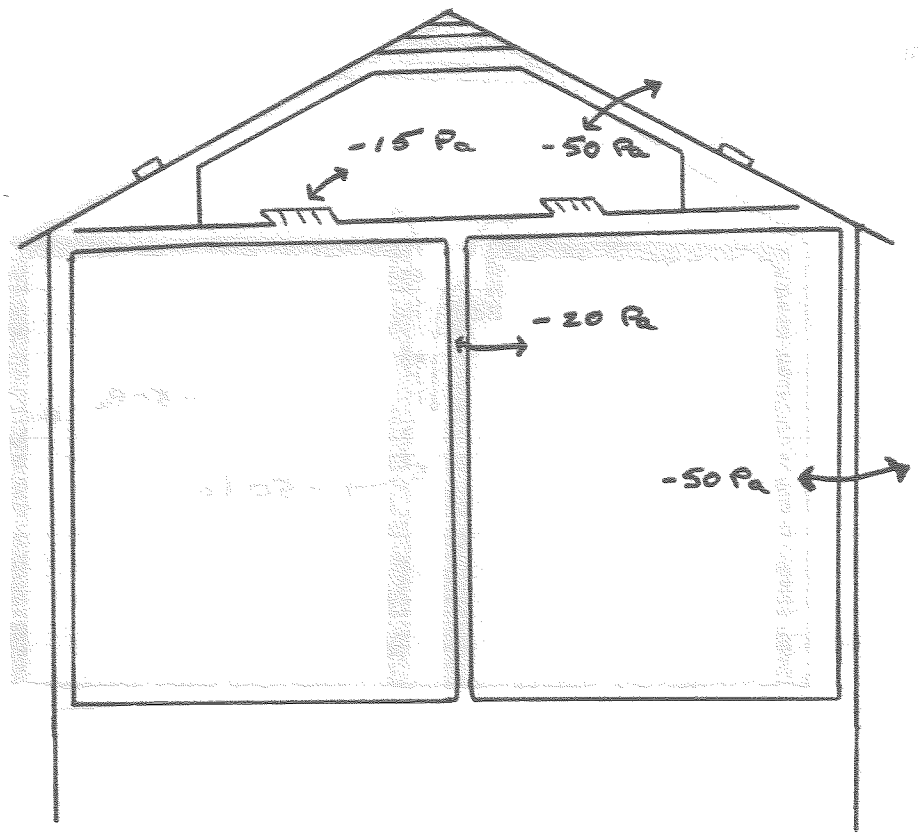
A story and a half house has interconnections between the basement, sidewalls and interior wall cavities to the first floor ceiling joists, kneewall attics and the peak attic. The house uses a first floor ceiling joists as a return chase for the upstairs. We measure a 15 Pa pressure at a second floor return register (with a pressure pan) 20 Pa pressure between the house and an interior wall cavity. What are the implications?

- As treatments are applied to the attic and sidewalls, the blower door shows minimal reduction. Only when the final treatment is complete does the blower door reading respond. When leaks are interconnected, all edges of the leakage path must be sealed to get the full blower door reduction.

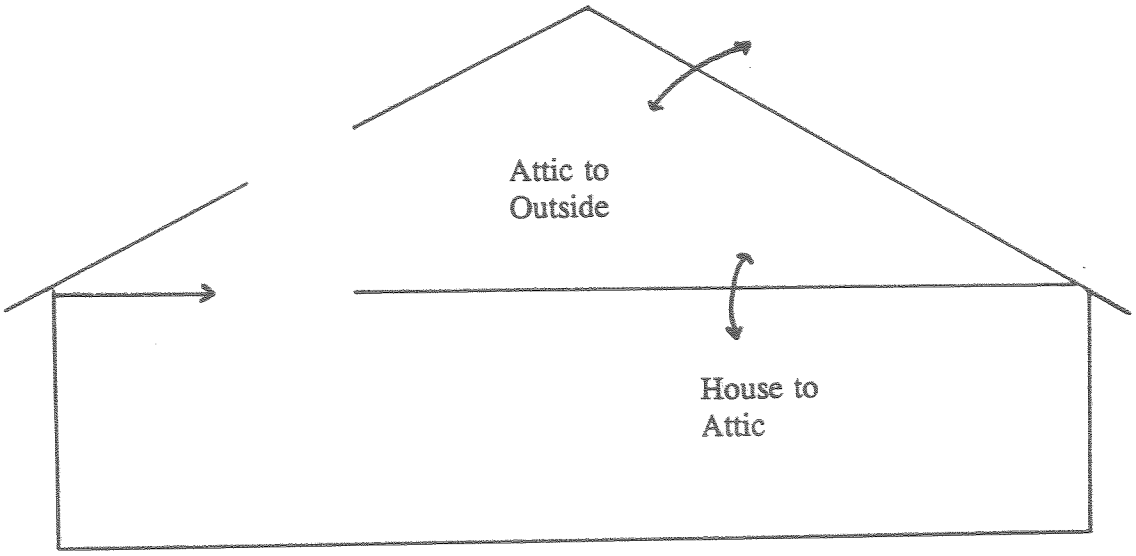
- Using building framing for duct runs typically creates leakage between the duct system and outside. In this case, the return duct leak disappears when we effectively seal the ends of the ceiling joist which contain the return ductwork.

Interconnected House:

Pressure Boundary is Complicated



Series Leakage Paths: Relationship between Leakage Rates and Pressures



Relative Size of Leakage Rates		Measured Pressures *	
Leakage From House to Attic	Leakage From Attic to Outside	House to Attic	Attic to Outside
2	1	-12	-38
1	1	-25	-25
1/2	1	-37	-13
1/3	1	-41	-9
1/4	1	-45	-5
1/8	1	-48	-2
1/13	1	-49	-1

The table above gives the relative size of the leakage rates. However, you need to know the actual size of one side of the leakage path (house/attic or attic/outside) to determine if the leakage path is significant.

* With the house depressurized by 50 Pa.

Simplified Pressure Diagnostics Procedure

Try to find the pressure boundary of the house with a few simple pressure measurements. Is the attic more outside or inside the house? Is the basement or crawlspace connected more to the house or more to the outside? Are forced air ducts connected to the outside?

1. Measure baseline house to attic pressure, and house to outside pressure.

2. Close accessible attic vents to better measure the effect of attic bypasses.

3. Depressurize house by 50 Pa from baseline house to outside pressure.

4. With house depressurized by 50 Pa, measure the following pressures:

    - house to attic (subtract baseline house to attic pressure from measured house to attic pressure)

    - house to other zones

    - house to ductwork (pressure pan)

5. Quantify the portion of whole house leakage (CFM50) that comes through the attic, other zones or duct system using calculation procedures.

6. Interpret results to decide what is the most important treatment to do first, and which leakage sites are interconnected.

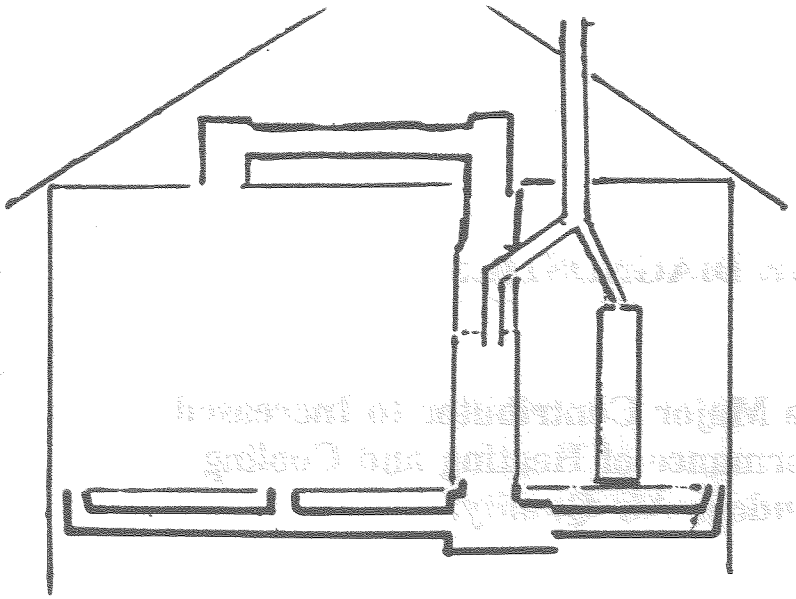
BEFORE CONDUCTING DIAGNOSTIC PROCEDURES, SET UP THE HOUSE SO THAT YOU MEASURE THE IMPORTANT LEAKAGE SITES

PUT DUCTWORK INSIDE OR OUT?

PUT BASEMENT INSIDE OR OUT?

OPEN ATTIC OR CRAWLSPACE VENTS?

DUCT LOCATION



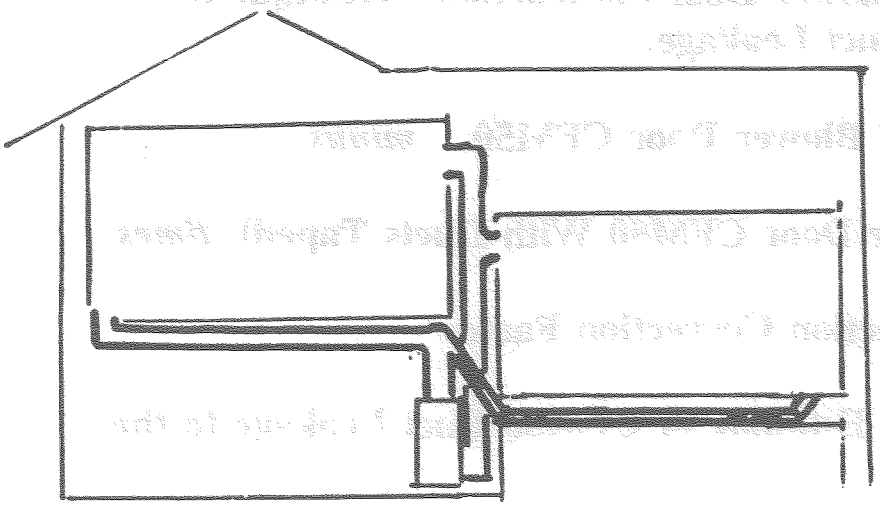
"outside"

-verify duct zone pressure same as outside

-test with pressure pan

-seal ducts before shell until pan numbers below 1pa

-seal largest leaks, closest to the air handler first. use mastic, mesh, and metal



"mixed"

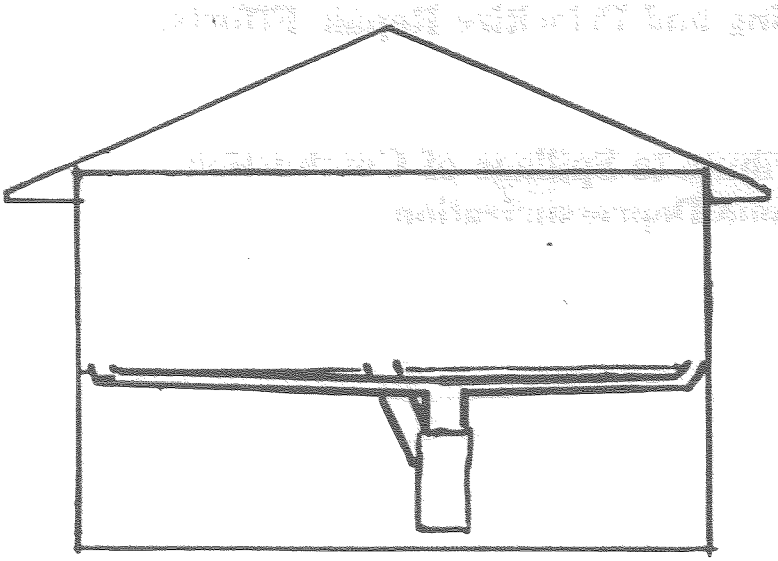
-determine proper location of thermal boundary.

-seal ducts outside as above, seal duct chases at thermal boundary and proceed as below.

-retest with pressure pan after shell sealing done.

-interconnected leaks require all edges done before final.

-"inaccessible" means use dense pack



"inside"

-open basement door to upstairs to place duct zone inside.

-seal shell before ducts, esp. all cavities containing or used as ducts, at thermal boundary, (fix air barrier) verify with pressure pan.

-seal big supply leaks in basement if usage or comfort problem. Seal returns until no negative pressure caused by HVAC fan in basement.

-pressure relieve rooms

DUCT LEAKAGE DIAGNOSTICS

- **Duct Leakage Can Be a Major Contributor to Increased Energy Use, Poor Performance of Heating and Cooling Equipment, and Poor Indoor Air Quality.**

- **Modified Blower Door Subtraction Technique to Measure Duct Leakage.**

  (Initial Blower Door CFM50 ***minus***

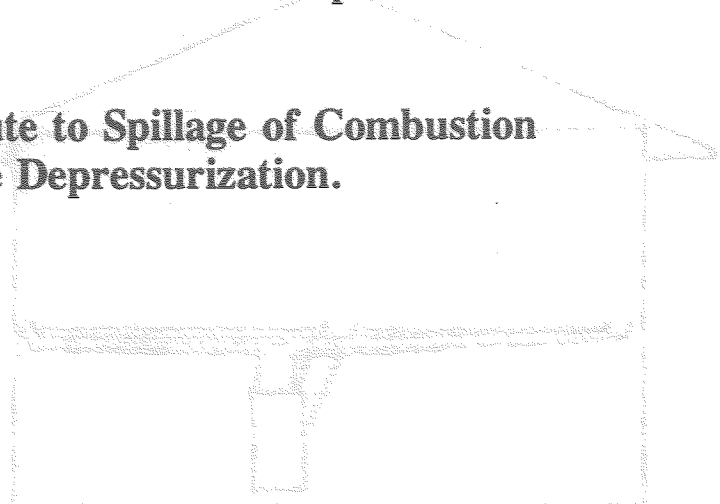
  Blower Door CFM50 With Ducts Taped) ***times***

  Subtraction Correction Factor

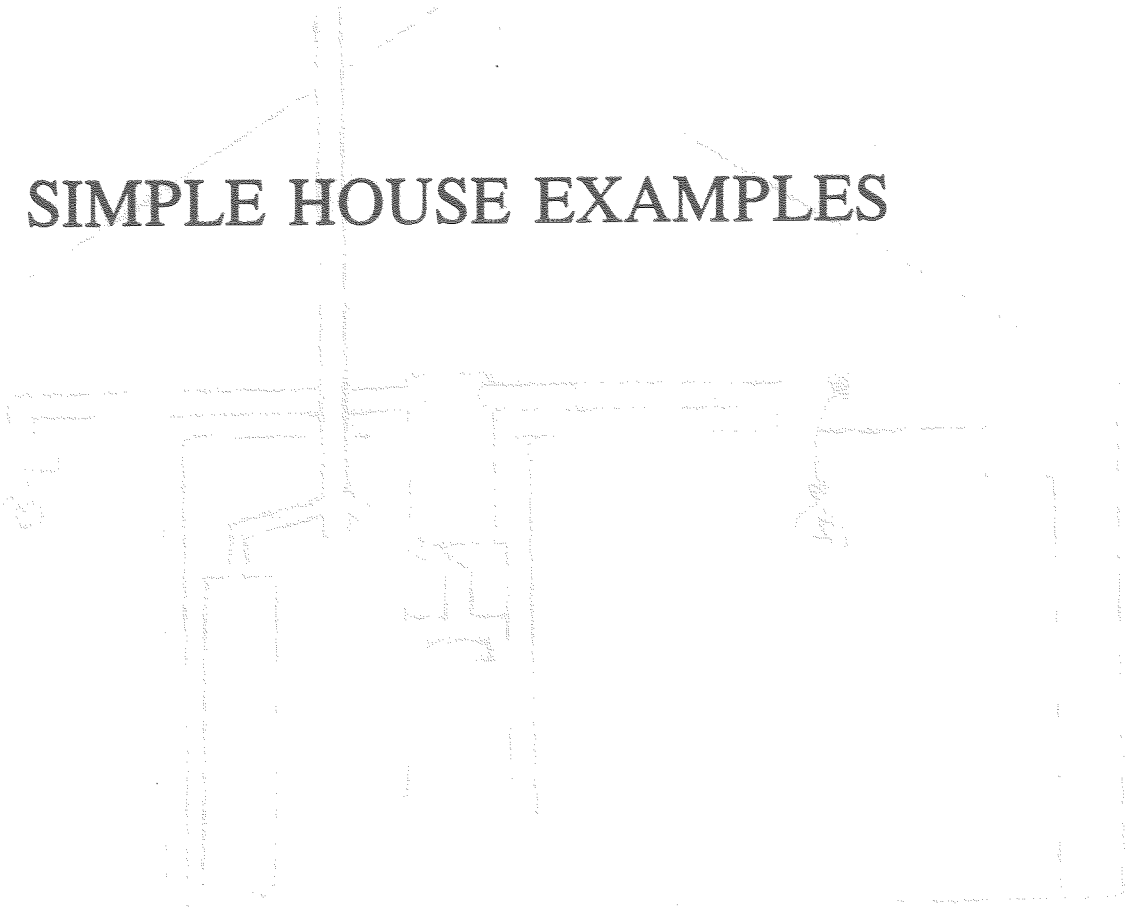
  Provides an Estimate of CFM50 Duct Leakage to the Outside.

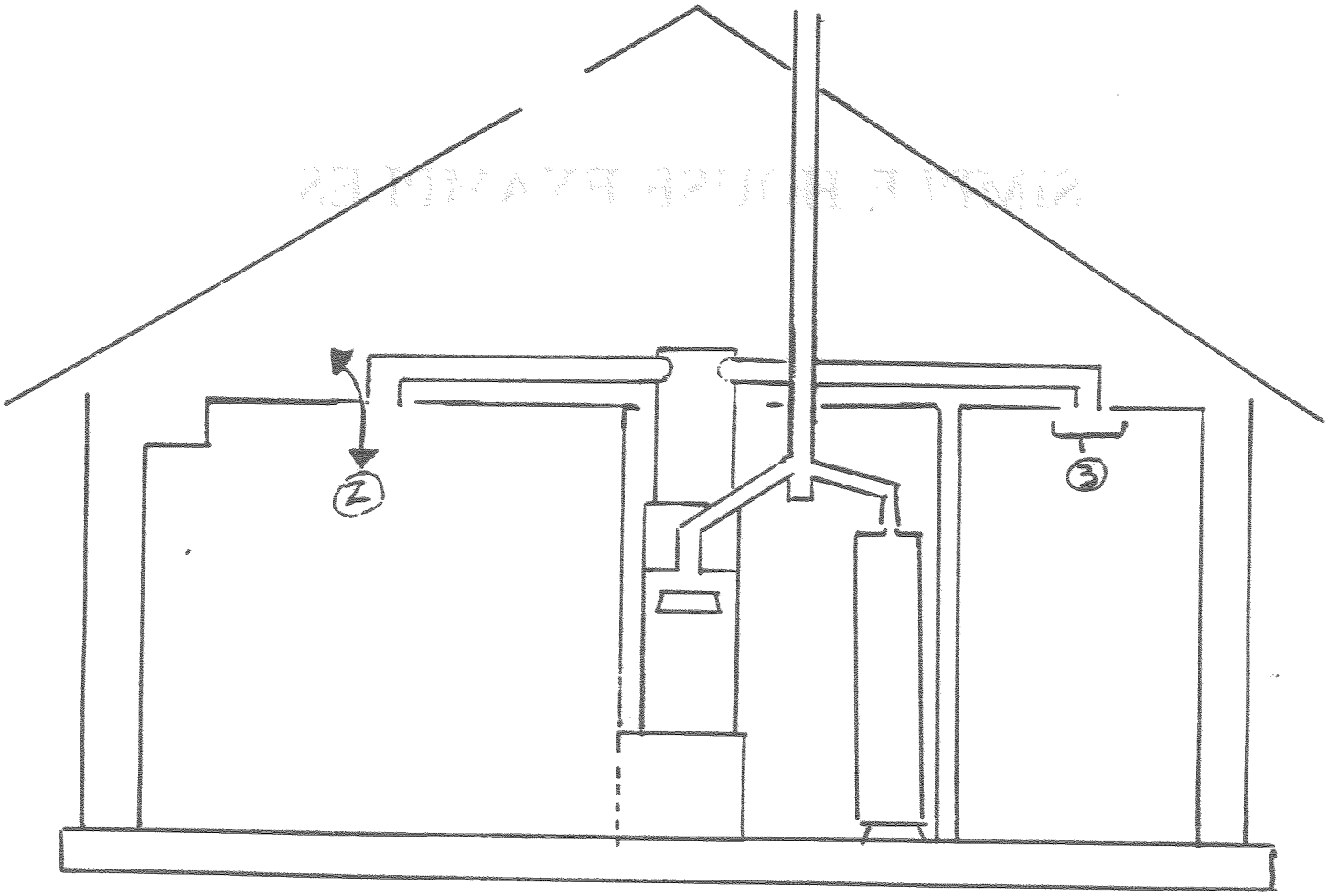
- **Pressure Pan/Smoke Measurements Help Determine Which Ducts are Leaking and Prioritize Repair Efforts.**

- **Duct Leaks Can Contribute to Spillage of Combustion Appliances Through Zone Depressurization.**



SIMPLE HOUSE EXAMPLES



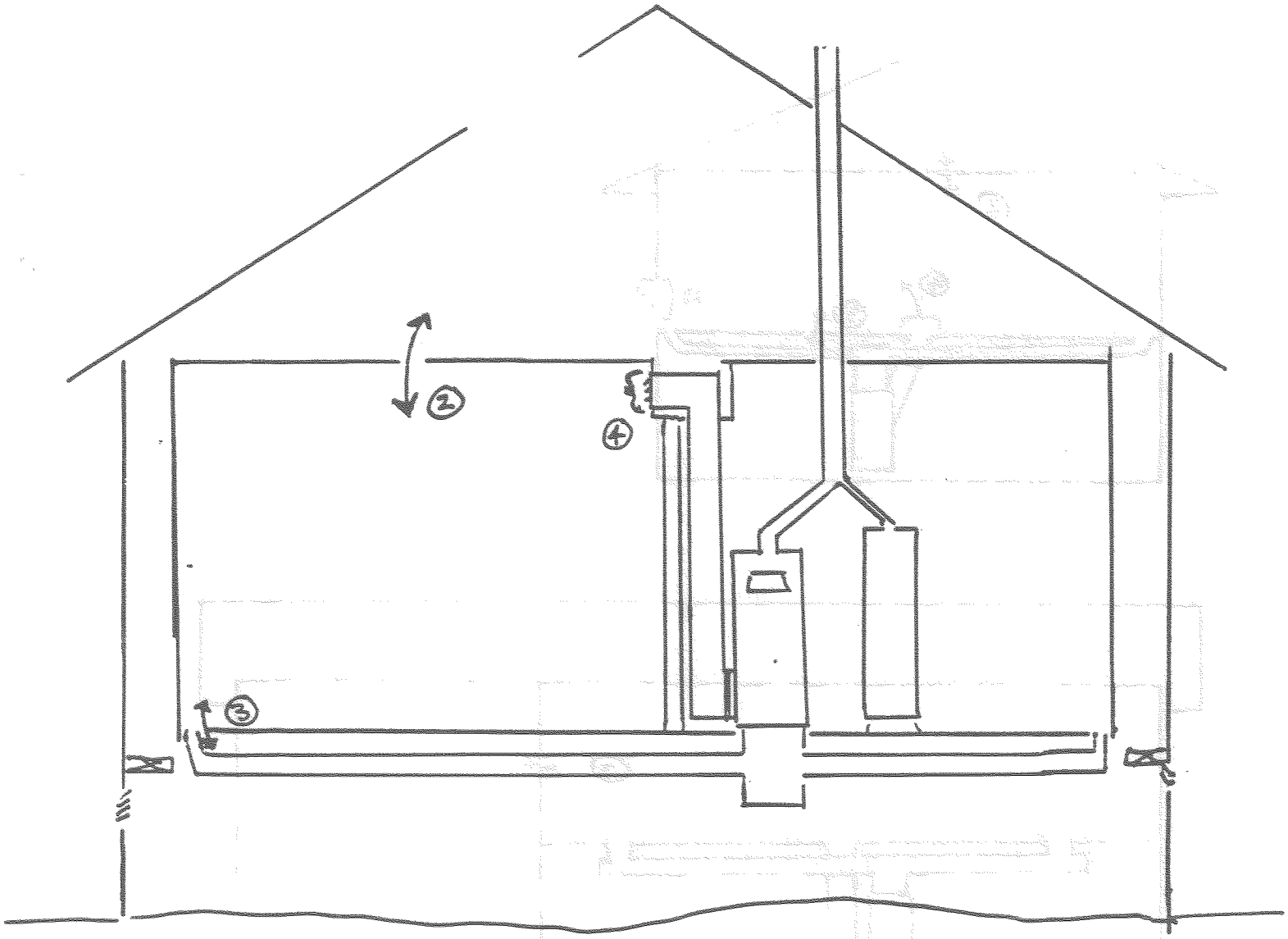


Safety Check ____

With House Depressurized by 50 Pa:

1. CFM50 ___
2. House to Attic Pressure ___
3. House to Duct Pressure (Pressure Pan) ___ ___ ___ ___

   ___ ___ ___ ___
4. Predict need for Ventilation ___



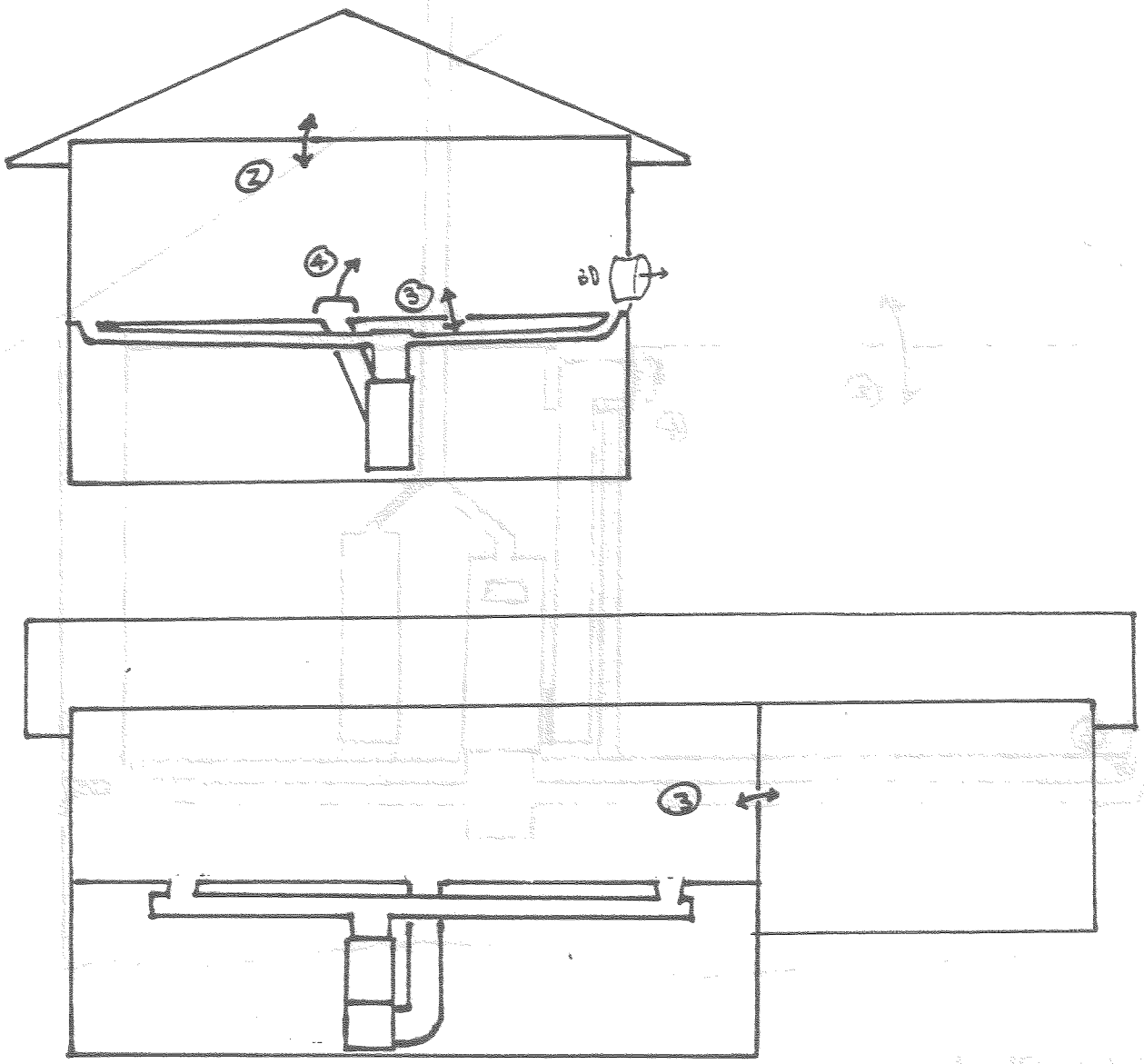
Safety Check ____

With House Depressurized by 50 Pa:

1. CFM50 ___
2. House to Attic Pressure ___
3. House to Crawlspace Pressure ___ (seal or vent? ____)
4. House to Duct Pressure (Pressure Pan) ___ ___ ___ ___

___ ___ ___ ___

Seal Ducts or Duct Chase? ___ Apply Ground Cover? ___



Safety Check ____

With House Depressurized by 50 Pa:

1. CFM50 ___
2. House to Attic Pressure ___
3. House to Other Zones Pressures ___ ___ ___
4. House to Duct Pressure (Pressure Pan) ___ ___ ___ ___

COMPLEX (INTERCONNECTED) HOUSE EXAMPLES

To Assess InterConnection:

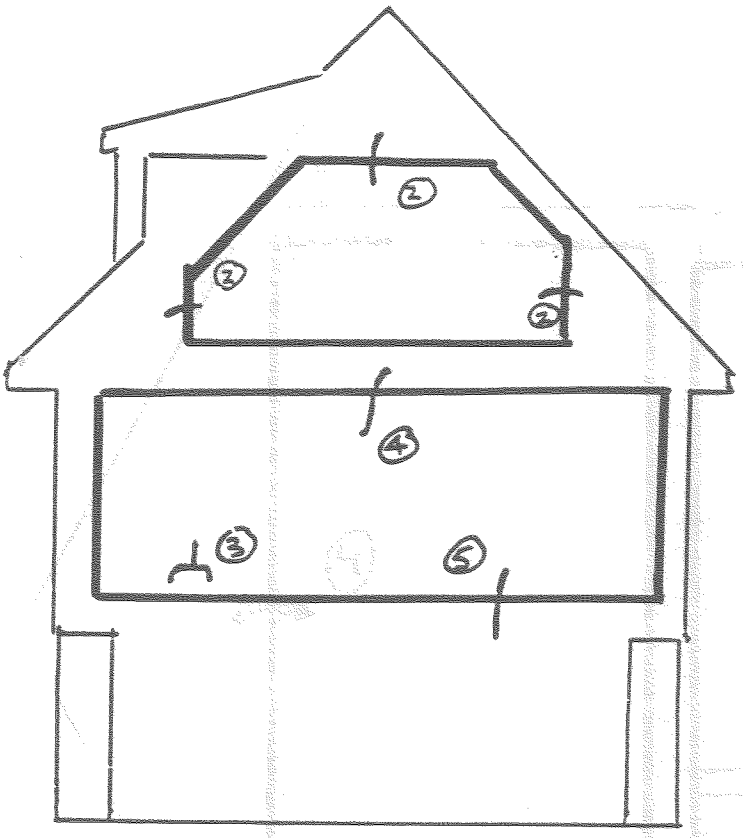
Depressurize house to 50 pascals.

Set gauge to measure Zone A, attic, side attic, basement, garage, other.

Open door to Zone B, and readjust blower door to read 50 again.

If they are connected, the pressure in A will change, if not, A will not change.

If they are fully connected, all edges of the same leakage path must be done to get full blower door reduction



Safety Check ____

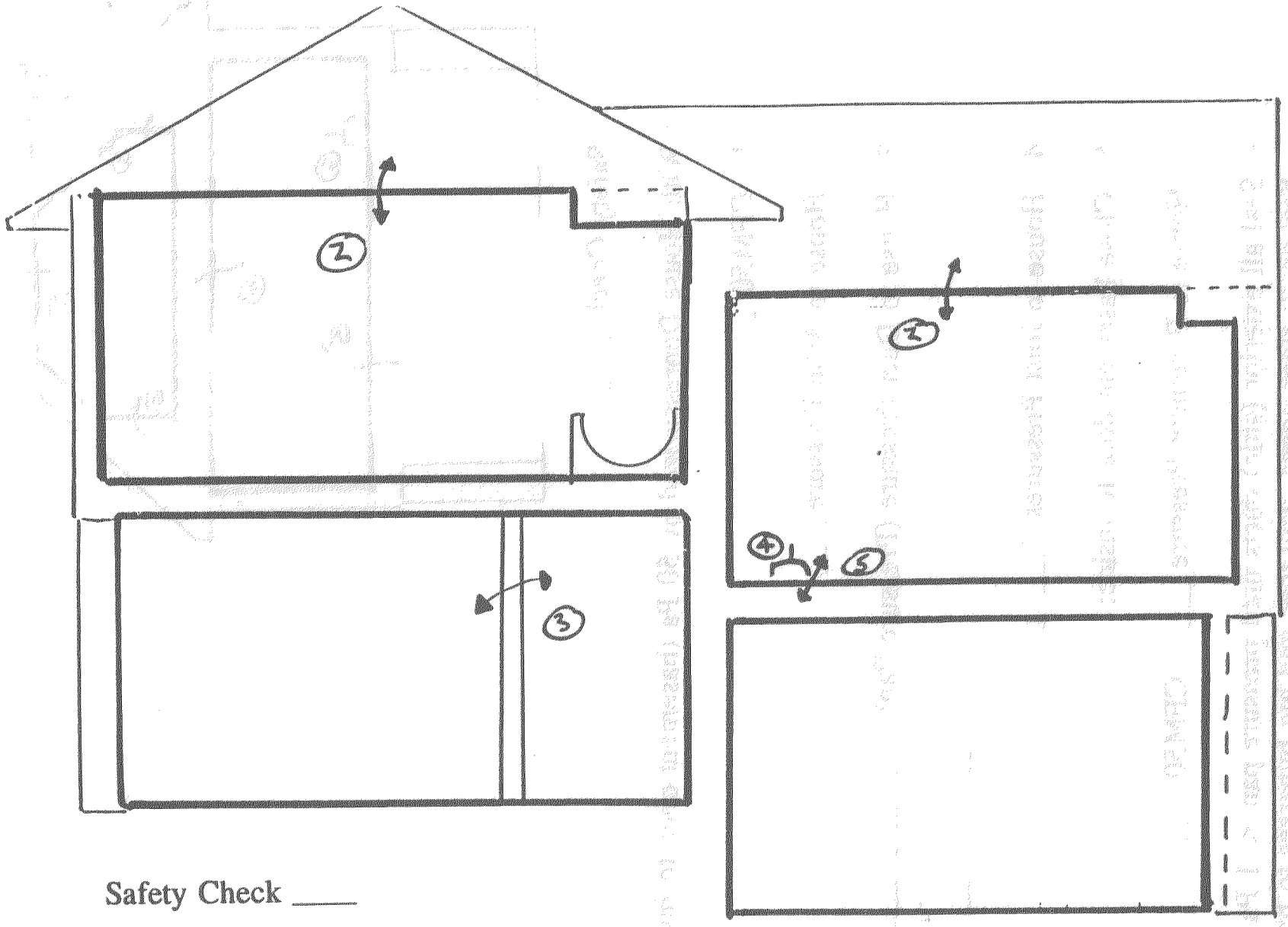
With House Depressurized by 50 Pa (basement open to inside):

1. CFM50 ___
2. House to Attic Pressure ___
3. House to Duct Pressure (Pressure Pan) ___ ___ ___ ___

   ___ ___ ___ ___
4. House to Joist Pressures ___ ___
5. Close basement door to inside:

   House to Basement Pressure ___ CFM50 ___

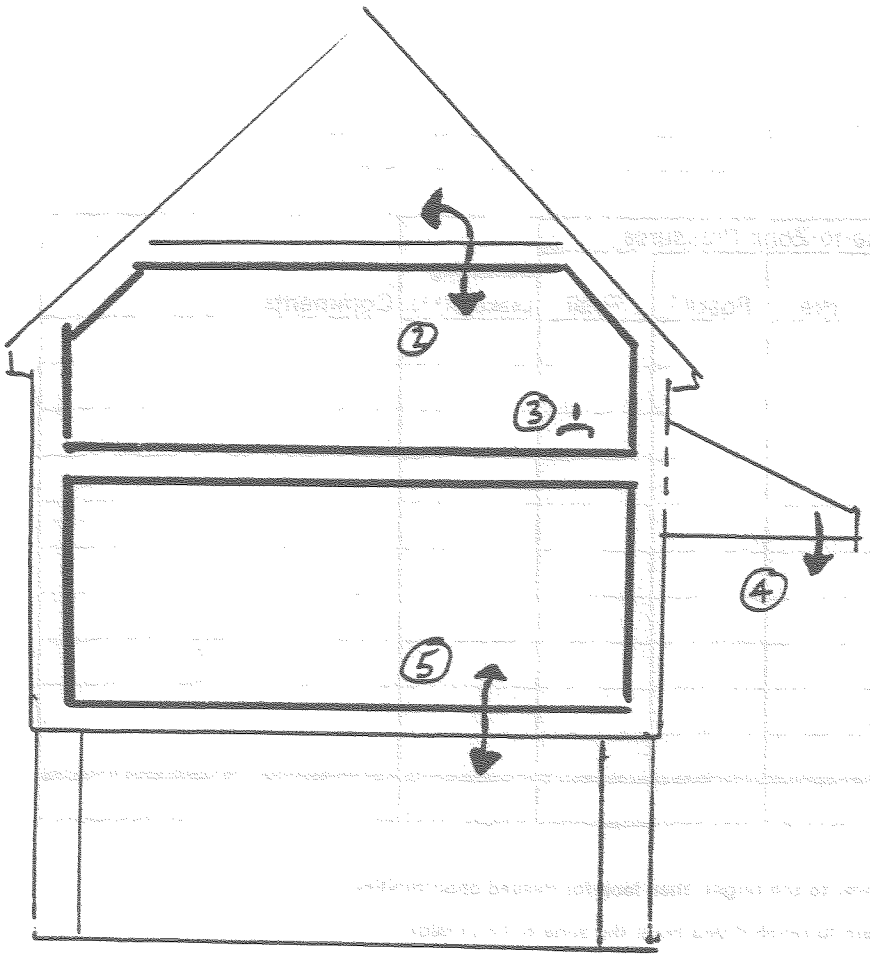
- Seal all exterior (attic) ducts until pressure pan < 1 Pa.
- Seal shell: floor edges, wall tops and big bypasses to bring other ducts completely inside air barrier (pressure pan < 1 Pa).
- Seal large supply leaks in basement, seal returns until no negative pressure between basement and outside with air handler on (BD off).



Safety Check ____

With House Depressurized by 50 Pa (basement open to inside):

1. CFM50 ____
2. House to Attic Pressure ____
3. House to Garage Pressure ____
4. House to Duct Pressure (Pressure Pan) ____ ____ ____ ____
5. House to Duct Joist Pressure ____
   - Seal ducts or duct cavity?



Safety Check ____

With House Depressurized by 50 Pa (basement open to inside):

1. CFM50 ____ 2. House to Attic Pressure ____

3. House to Duct Pressure (Pressure Pan) ____ ____ ____ ____

4. House to Porch Roof Pressure ____

5. Close basement door to inside: House to Basement Pressure ____

- Seal all exterior (attic) ducts until pressure pan < 1 Pa.
- Seal shell: floor edges, wall tops and big bypasses to bring other ducts completely inside air barrier (pressure pan < 1 Pa).
- Seal large supply leaks in basement, seal returns until no negative pressure between basement and outside with air handler on (BD off).

PRESSURE DIAGNOSTICS

Job ID:_____ Address:_____

Safety Tests Done_____

Testing Notes (windy, existing pressures, house set-up, etc.):_____

_____

Zone Tested:	Estimated Leakage to Outside	House-to-Zone Pressures				Remaining Leakage(**)	Comments
		Target(*)	Pre	Post#1	Final		
Attic		50					
Basement							
Crawlspace							
Garage		50					
House CFM50							

NOTES:

1) If your work doesn't make the pressure much closer to the target, then look for missed opportunities
2) If outside is tight, then target pressure may be hard to reach if you want the zone to be outside
3) If Pre pressure is far from target, then CFM50 won't change much until you've sealed most leaks because the blower door doesn't show convective loops

* Pressure Target = 50 if we want the zone to be outside or 0 if we want the zone inside

** You must calculate final leakage if Final Pressure is more than 2 pascals away from target use add-a-hole or open-a-door to prove that leakage is small

Pressure Pan Readings

Register	Pre	Post

Register	Pre	Post

Safety Tests Re-Done after all work complete____

MB / JF - 8/12/93

STEP BY STEP PROCESS

1) Determine Retrofit Potential: client/occupant needs, fuel usage (all sources), safety, durability concerns & history.

2) Observe exterior and interior condition for: obvious problems, safety-moisture signs, odors or fumes, possible direct and hidden air leakage, approximate attic venting, inside and outside temperatures.

3) Safety check: structure, electrical, combustion safety, IAQ and occupant's special needs and ability to help/maintain.

   (** At This Point Decide: stop and get help, continue diagnosis or start work)

4) Conduct CFM50 pre-retrofit blower door test with additional measurement of key zone pressures to inside. Conduct IR scan with blower door running if house previously weatherized. Locate breaks in thermal and air barriers.

   (** At This Point Decide: need for client ed., mechanical ventilation, furnace work, duct sealing, airsealing, insulation, targeted dense-pack, or some combination. Set budget, scope of work and order of work.)

5) Control Sources: fix gas leaks, CO, etc., replace faulty equipment (with correct size equipment), fix wiring hazards, fix roof or plumbing leaks, install poly ground cover, install quiet continuous duty fan near source of moisture and vent outside.

6) Seal all exterior ducts, with big leaks near the air handler as first priority. Use metal, mastic, mesh tape and insulate exterior ducts better than the building shell.

7) Dense-pack key junctures and hidden leakage sites, or pack all closed floor, roof and wall cavities. Use > 4#/ft3. Pack tops of all walls leaking air into inaccessible attics.

8) Seal all attic air leaks and convective loops. Install blocking or hand pack exterior top plate to stop wind washing. Seal all large basement or crawlspace leaks.

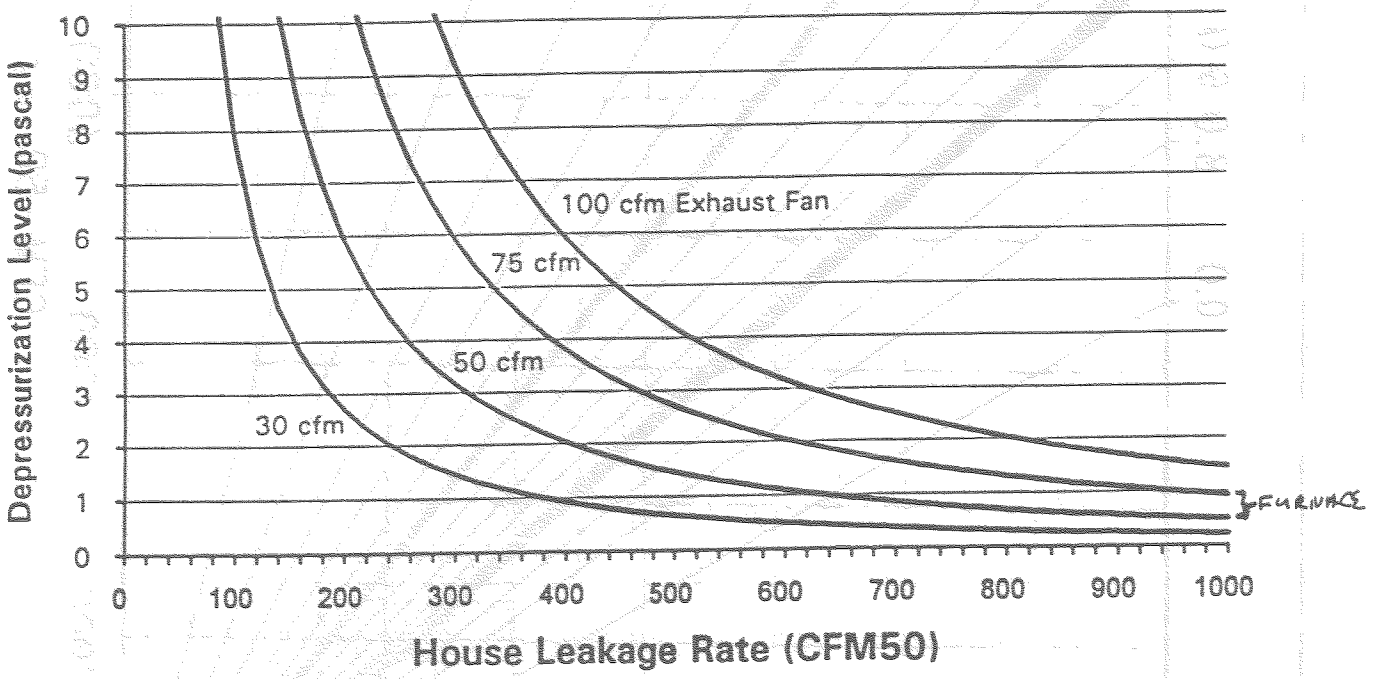
9) Conduct mid-point blower door test and re-measure key pressures.

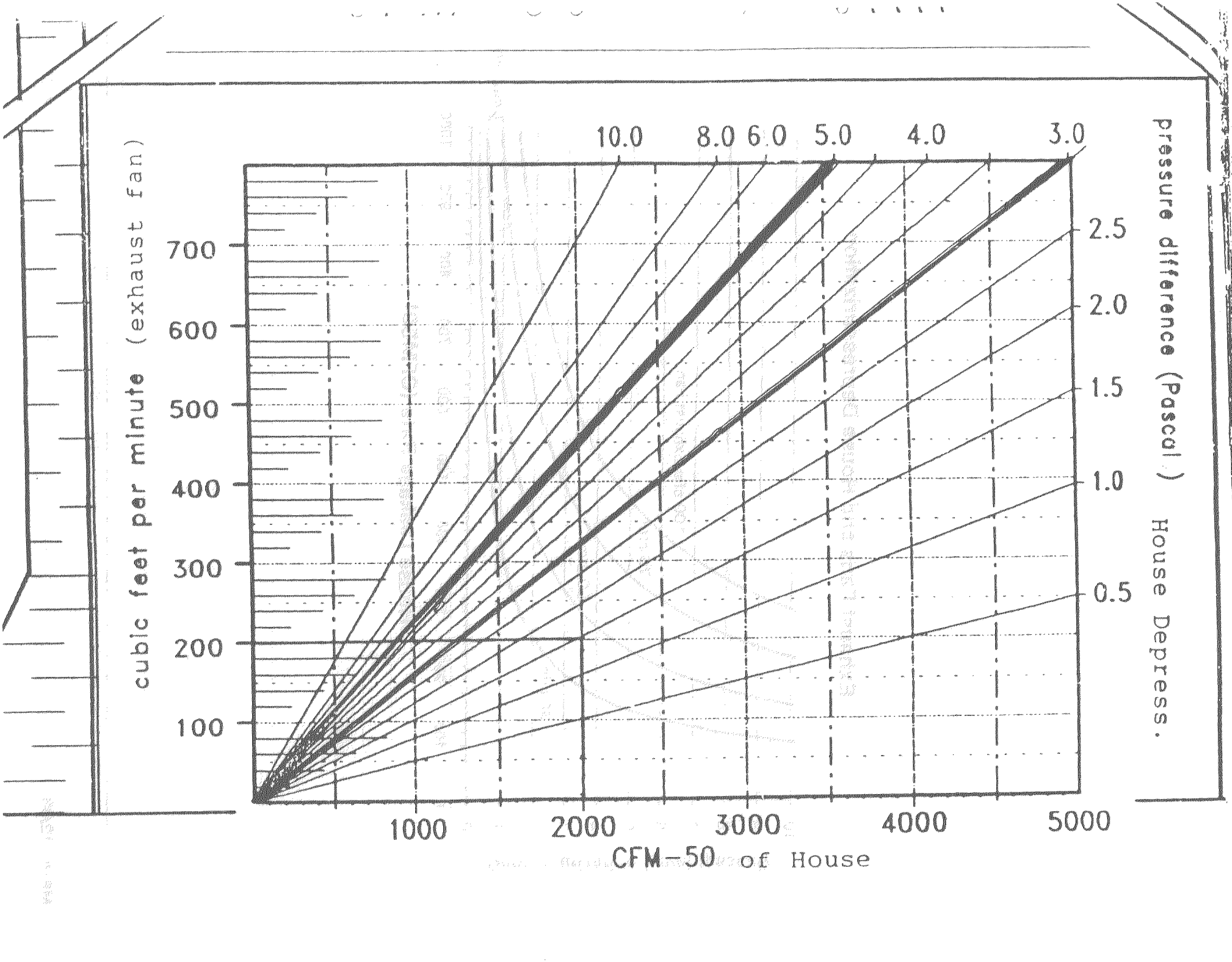
10) Continue sealing if tests indicate you are not done. Install ventilation fan if "too tight" after attic is sealed.

11) Seal interior/basement duct leaks and conduct pressure balancing to reduce negative pressures in combustion zone.

12) Final Safety Tests.

Exhaust Fans and House Depressurization




10.0
8.0
6.0
5.0
4.0
3.0
cubic feet per minute (exhaust fan)
700
600
500
400
300
200
100
pressure difference (Pascal) House Depress.
2.5
2.0
1.5
1.0
0.5
1000
2000
3000
4000
5000
CFM-50 of House

Health and Safety Action Guide

Tests To Be Performed	Health and Safety Issue	Questions/Procedures/Guidelines	Action/Comment
Measure ambient CO level house/kitchen upon entry.	CO is a dangerous combustion byproduct which can cause serious illness or death.	- Investigate any levels above 2ppm. - Maximum Guidelines: 9 ppm for 8 hr exposure (EPA) 35 ppm for 1 hr exposure (EPA) 200 ppm for single exposure (OSHA)	CO concentrations at or above these levels requires immediate remedial action.
Visual Inspection/Client Interview on H. & S.	Use eyes, nose and client to find existing H. & S. problems.	- Are unvented space heaters present? - Is there existing moisture damage or wet basement or crawlspace? - Are dangerous household chemicals stored improperly?	If any of these conditions exist, no airtightening should be performed until problem is remedied.
Inspect Combustion Appliances.	Inspect appliances for obvious H. & S. problems.	- Gas or Oil leaks? - Deteriorated flue pipes/connections? - Signs of spillage/flame rollout?	Gas or oil leaks require immediate remedial action. Deteriorated flues, spillage or rollout should inspected by htg. contractor.
Blower Door Airtightness Test Results.	Determine if estimated natural ventilation rate of house is adequate.	- Compare existing/final CFM50 with calculated Building Airtightness Guideline.	If CFM50 is below Building Airtightness Guideline, install necessary mechanical ventilation.
Worst-Case Depressurization Test.	Determine the potential of exhaust fans or air handler to cause spillage of combustion byproducts from natural draft appliances into the house.	- Conduct "Worst-Case Fan Depressurization" Test.	If House Depressurization Limits (HDL) are exceeded, provide pressure relief for combustion appliance zone, or inform client of proper fan operation and implications on safety.
Combustion Safety Tests	Determine the presence of unsafe combustion appliances, or venting conditions.	- Conduct "Spillage Test" on all operating combustion appliances under worst-case conditions. - Conduct "Draft Test" on all operating combustion appliances under worst-case conditions. - Conduct "CO Test" on all operating combustion appliances. - Conduct "Heat Exchanger Integrity Test" on all forced air furnaces.	If any combustion safety tests indicate a problem with the combustion appliance, contact a htg. contractor for immediate inspection.