AABC Commissioning Group

AIA Provider Number 50111116

Fundamentals of Test, Adjust, & Balance for Engineers, Cx & Energy Providers

Course Number: CXENERGY1909

Jim Hall, P.E., TBE, CxA

Systems Management & Balancing, Inc.

April 17, 2019

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Course Description

This practical, information-packed session explains many of the key test and balance challenges—from practical system design considerations, to the TAB Process, to obtaining meaningful and useful data—that if properly addressed in cooperation with an independent TAB firm can ensure that any project goes smoothly.

Learning Objectives

At the end of the this course, participants will be able to:

1. Understand the proper use, application, and limitations of the TAB instrumentation.

2. Understand what is accurate, useful and meaningful data that is obtained in the field vs. laboratory data for use on their project.

3. Gain an understanding of HVAC systems and the TAB/measurement process; how can systems be set up to allow for proper data collection.

4. Promote a project team approach to address schedule challenges, design alternatives as it relates to balancing device locations, equipment usage and HVAC system operation.

The majority of the presentation covers air systems, if time permits there are a few slides at the end on water systems that can be reviewed.

Learning Laboratories

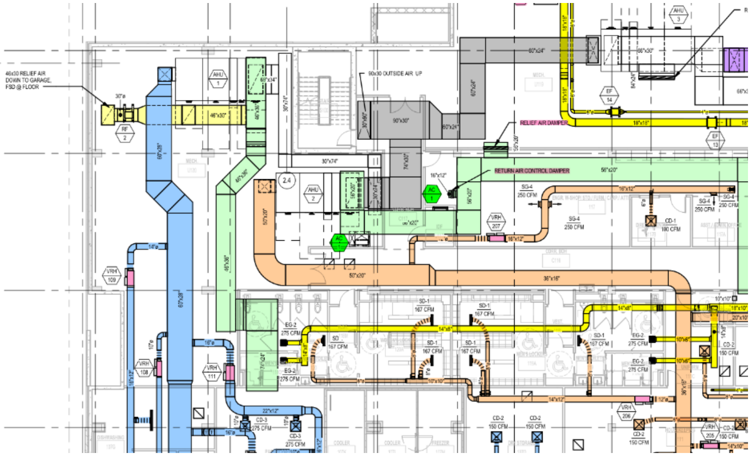
- The TAB Agency is fortunate….every project is a potential Learning Laboratory
- We are not promoting "shortcuts", we are trying to share experiences for improving industry knowledge
- **Lessons learned need to be shared**

Project Document Review

- One of the most beneficial and productive parts of the TAB & Cx process is a **specification & drawing review.**
- **START EARLY** – During or before design if possible
- Utilize **common sense**; what is the goal or intent?
- Review **system functionality**; Are balancing dampers & valves strategically placed? Is there proper access to equipment/systems?
- If the CxA is utilizing the project specifications to establish PFC's and FPT's make sure they are applicable – A Project **Specific** Specification

Project Document Review

- TAB Data is a byproduct of:
  - System Design
  - Equipment Selection
  - System Installation
  - System Operation
  - Proper use of TAB instrumentation

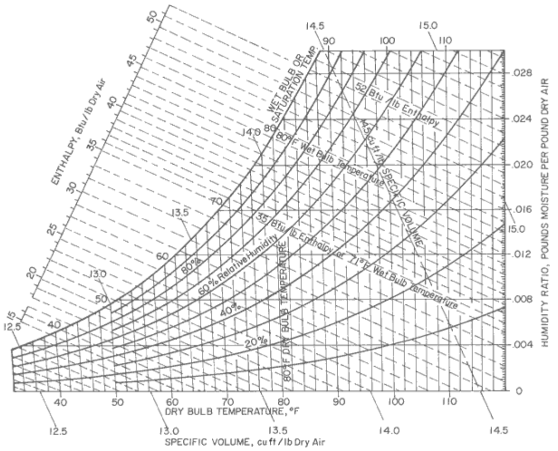


TAB Data

- Understand what is **meaningful data**. Discuss with the design professional if the specified data is relevant or useful.
- Will the data **benefit the owner and project**?
- Try to think of how data will be obtained and what data will be required.
- Do not get hung up on getting data/numbers, **think system!!**

TAB Data

- Will the requested data be **Accurate, Repeatable and Meaningful?**
  - Example – Wet-bulb temperatures
    - Can a latent load be established?
    - Temperature traverse is required, not a single point temperature measurement.
    - Maintain the proper air velocities
    - Maintain proper water flow and water temperatures, DX operation, etc.



System Design/Equipment Selection

- Can outdoor air be measured to AHU?
  - Is there enough ductwork for a proper traverse?
  - Does unit configuration allow for proper measurement?
- Can outdoor air be measured to RTU?
  - Is the RTU configured/installed for outdoor air measurement?
  - If mixed air temperature method is utilized can an accurate mixed air temperature be measured?
  - Static pressure profile of RTU or outdoor duct/equipment; make sure "factory or weatherproof test ports" are installed.

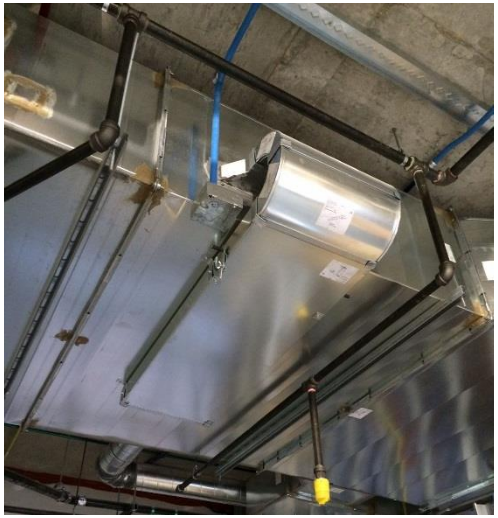
System Design/Equipment Selection/TAB Instrumentation
Airflow Measurement – Traverse Locations

- The **primary/preferred airflow measurement** method is a **duct traverse.**
- **Ideal traverse plane**:
  - For **round duct,** AABC, AMCA & ASHRAE all identify the ideal traverse plane as 2 ½ diameters from condition (discharge, elbow, etc.) for up to 2500 fpm. Add 1 diameter for each additional 100 fpm.
  - For **rectangular duct,** $E_L = (4a*b/\pi)^{0.5}$, where "a" & "b" are the duct dimensions.
  - Accuracy of the traverse is better at 1000 fpm or above.

System Design/Equipment Selection/TAB Instrumentation
Airflow Measurement – Traverse Locations

Example:

- 10,000 cfm, 30″ x 20″ duct, 2400 fpm
- $E_L = (4a*b/\pi)^{0.5} = 27.6''$
  2 ½ * 27.6″ = 69.1″
- 69.1″ (~ 6′) straight duct required



System Design/Equipment Selection
Traverse Locations **Alternatives**

A duct traverse can still be performed if an ideal traverse plane is not available.

- A traverse plane is suitable for flow measurements if more than 75 % of the velocity pressure readings are greater than 1/10 of the maximum velocity measurement and are not negative
- Use TAB instrumentation correctly; a thermal anemometer measures air velocity in one direction only. It will report a reverse airflow as a positive number.

Alternatives to Traverse

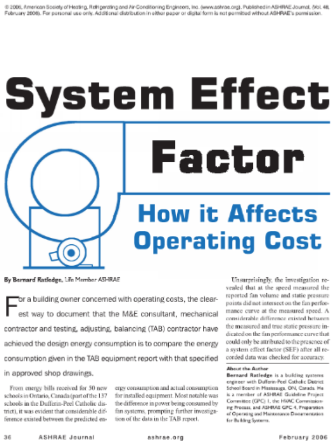
Only if a duct traverse is NOT accurate:

- Face velocity reading of filters, coils, etc.
- Summation of airflows at individual outlets
- Summation of calibrated VAV boxes as read at the DDC computer

Traverse Locations - System Effect

If there is NOT a good traverse location for the fan/unit, then the possibility for System Effect and poor fan performance exists.

Reference AMCA Publication 201:2002 "Fans & Systems" for additional information on System Effect.



System Effect Factor

How it Affects Operating Cost

By Bernard Ratledge, Life Member ASHRAE

For a building owner concerned with operating costs, the clearest way to document that the M&E consultant, mechanical contractor and testing, adjusting, balancing (TAB) contractor have achieved the design energy consumption is to compare the energy consumption given in the TAB equipment report with that specified in approved shop drawings.

From energy bills received for 30 new schools in Ontario, Canada (part of the 137 schools in the Dufferin-Peel Catholic district), it was evident that considerable difference existed between the predicted energy consumption and actual consumption for installed equipment. Most notable was the difference in power being consumed by fan systems, prompting further investigation of the data in the TAB report.

Unsurprisingly, the investigation revealed that at the speed measured the reported fan volume and static pressure points did not intersect on the fan performance curve at the measured speed. A considerable difference existed between the measured and true static pressure indicated on the fan performance curve that could only be attributed to the presence of a system effect factor (SEF) after all recorded data was checked for accuracy.

About the Author

Bernard Ratledge is a building systems engineer with Dufferin-Peel Catholic District School Board in Mississauga, ON, Canada. He is a member of ASHRAE Guideline Project Committee (GPC) 1, the HVAC Commissioning Process, and ASHRAE GPC 4, Preparation of Operating and Maintenance Documentation for Building Systems.

How to Avoid This Increased Operating Cost?

- By not trying to save dollars per square foot by reducing the size of the mechanical room. The increased operating cost of the poor installation is likely to be far greater than the cost of providing the space necessary to ensure a good ductwork installation.

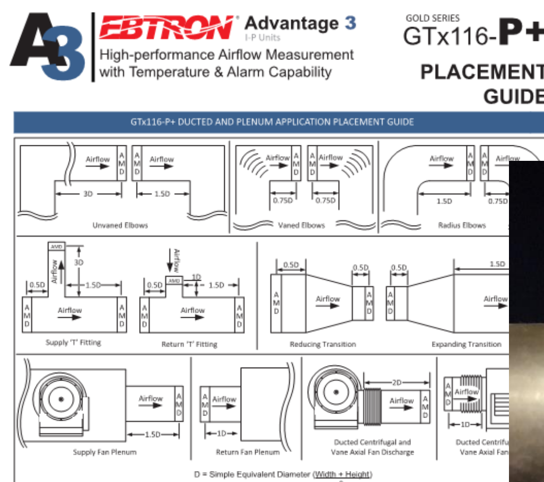
The increase in fan bhp = 16.83 – 10.06 = 6.77 (12.55 kW – 7.5 kW = (5.05 kW).

Using the same operating parameters as Example 1:

Based on the fan operating 245 days × 8 hrs/day × 7.5 = 14,700 kWh × $0.06/ kWh = $882 + 7.5 × $10/kW demand × 12 = $1,782/yr base electric cost. Revised operating cost with new motor = 245 days × 8 hrs/day × 12.55 = 24,598 kWh × $0.06/ kWh = $1,475.88 + 12.55 × $10/kW demand × 12 = $2,981.88/yr or $1,199.88/yr increase. A life-cycle analysis based on a school useful life of 25 years, annual energy cost escalation 5%, shows an estimated total additional operating cost of $86,489.

System Design/Equipment Selection
Airflow Monitoring Stations

- Requires calibration and maintenance
- **Requires filtered air**
- Will the AFMS work properly in the installed location? **Avoid air turbulence, follow manufacturers' installation guidelines**
- Will the AFMS work at **minimum airflow** and **maximum airflow** or vice-versa?
- Will the control damper create turbulence and measurement issues?



System Design/Equipment Selection
Measurement Tolerances

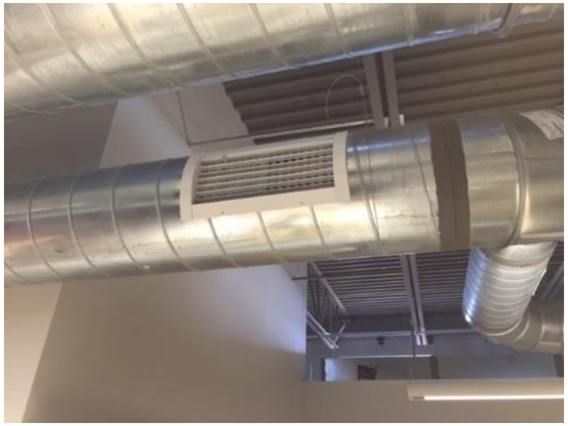
- **Think about ±5% or 0% to +10% tolerances**
  - May not be feasible, depending on the system and its components.
    - 0% to +10%; Is this realistic for how the system operates? Can the DDC system or the packaged equipment controls control to the tolerances specified?
  - Keep in mind, that in Labs and ORs, the main criteria for airflow is ACH and room pressurization. Typically the room envelope dictates the amount of airflow required to maintain proper room pressurization.
  - The TAB equipment manufacturer's tolerances sometimes are greater than the specification tolerances.

System Design/Equipment Selection
Balancing Dampers

- What is specified? What is installed? This can affect the TAB tolerances and system performance.

System Design/Equipment Selection
Balancing Dampers & Grills

- Accurate airflow measurement can be challenging on surface mounted grills
- **Never** rely on **face dampers** for air balancing
  - Face dampers add static to a system, but do not help divert airflow within the system
  - Can go closed or open due to system pressure
  - Can be noisy, the occupant can adjust, & they get dirty on exhaust systems
  - Required airflow tolerances are difficult to obtain



System Design/Equipment Selection

Insulation Requirements

- Make sure damper handles are exposed on externally wrapped ductwork

- Utilize test port extensions on balancing valves and all test ports

System Design/Equipment Selection
Control Systems

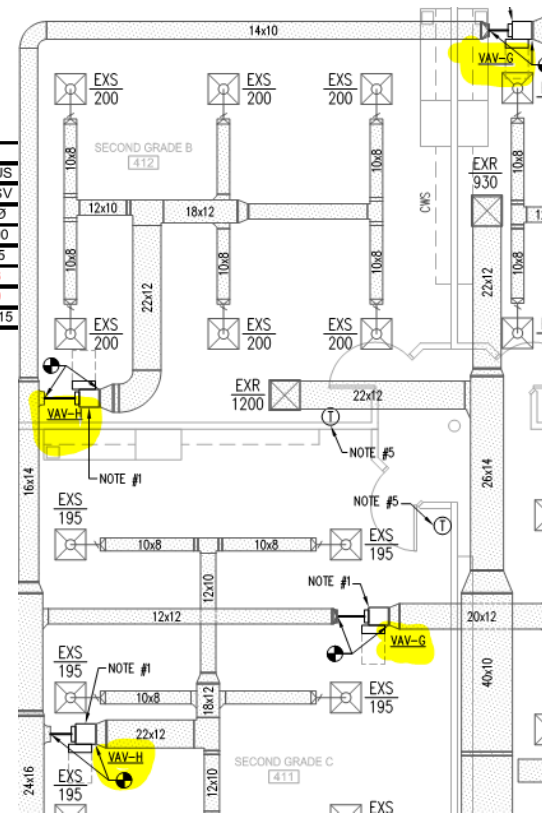
- Make sure that access to the control system is made available to the TAB agency and CxA. This includes any required hardware and software
- Know when the system “Front End” will be operational (sometimes the owner provides this hardware and/or network/internet connection)
- This seems to be a regional issue, not a manufacturer’s issue

System Design/Equipment Selection
Drawing Nomenclature & Equipment ID

- Help promote identifying each piece of equipment (fans, AHUs, HPs, VAVs, Pumps, etc.) with a **unique tag**.

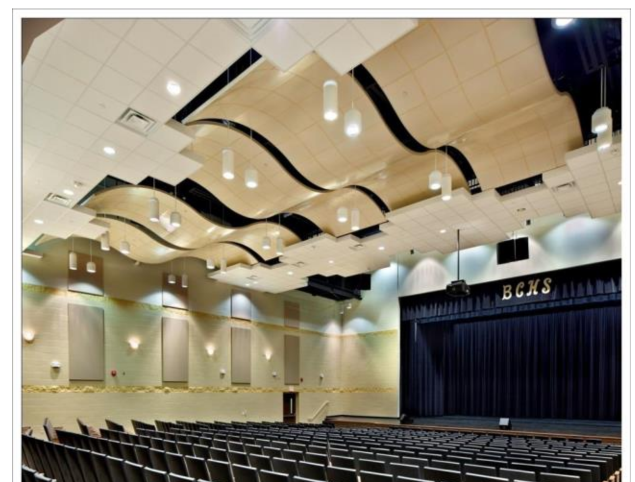
VARIABLE AIR VOLUME TERMINAL UNIT SCHEDULE

UNIT TAG	A	B	C	D	E	F	G	H
MANUFACTURER	TITUS	TITUS	TITUS	TITUS	TITUS	TITUS	TITUS	TITUS
MODEL NUMBER	DESV	DESV	DESV	DESV	DESV	DESV	DESV	DESV
INLET SIZE	4Ø	5Ø	6Ø	7Ø	8Ø	9Ø	10Ø	12Ø
BOX MAXIMUM AIRFLOW (C.F.M.)	150	200	300	450	600	850	1150	1700
BOX MINIMUM AIRFLOW (C.F.M.)	45	65	85	115	150	195	245	325
MAXIMUM NOISE LEVEL - DISCHARGE (NC)	11	11	10	13	17	15	18	18
MAXIMUM NOISE LEVEL - RADIATED (NC)	<15	<15	13	15	17	14	20	20
BOX DISCHARGE DUCT CONNECTION SIZE	12x8	12x8	12x8	12x10	12x10	14x12	14x12	16x15



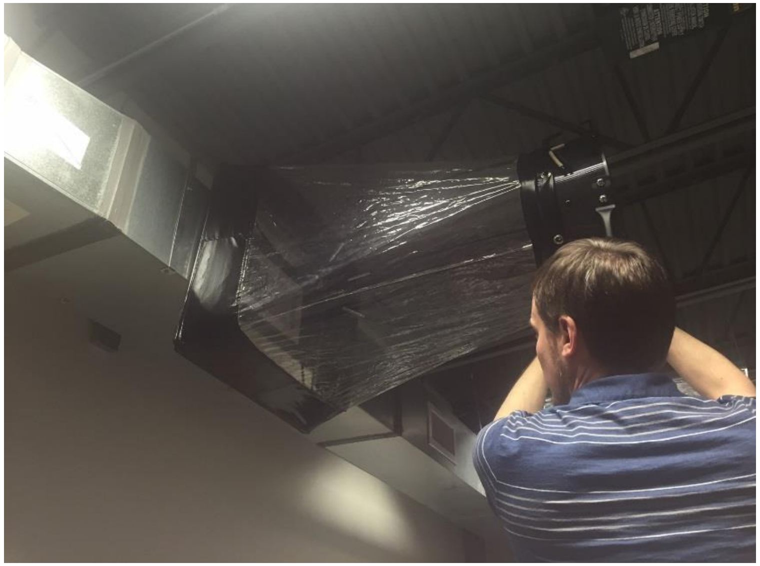
System Design/Equipment Selection
Access Challenges

- Proper clearance and access must be provided to all dampers, valves, equipment, etc.
  - Sheetrock ceilings, architectural features, etc.
  - Locate devices in the corridors outside of OR's, classrooms, etc.
- Access to outlets, dampers, etc. in theatre type seating areas. How will this be accomplished? AHU is typically not in operation when scaffolding is installed or future maintenance is required.



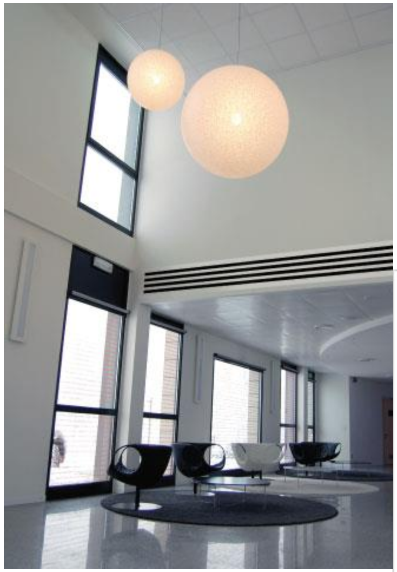
TAB Instrumentation
The Flow Hood

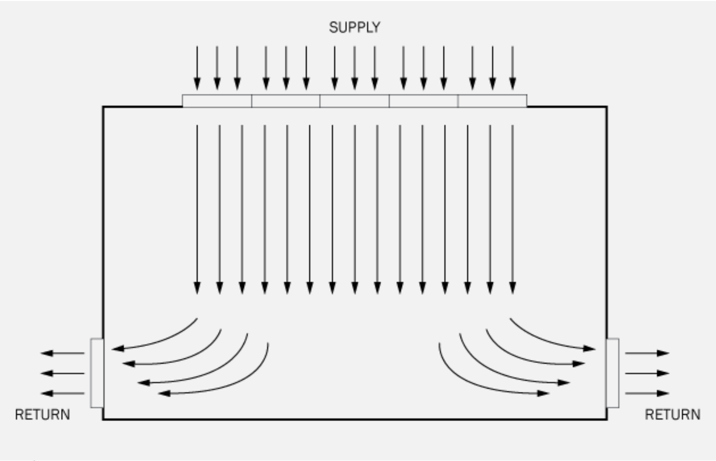
- The flow hood is a **proportioning device, NOT a airflow quantity measuring device.**
- Know the limitations of the flow hood and how it should be used.



TAB Instrumentation
The Flow Hood

The Flow Hood may require the development and use of correction factors when used on swirl diffusers, or on other types of diffusers with uneven air throw. The Flow Hood may not be appropriate for use on small supply outlets at high jet velocities or “nozzle” type outlets. These outlets cause an extreme concentration of air velocity on portions of the flow sensing grid. The Flow Hood readings may be inaccurate under such conditions. (Shortridge Instruments owners manual)



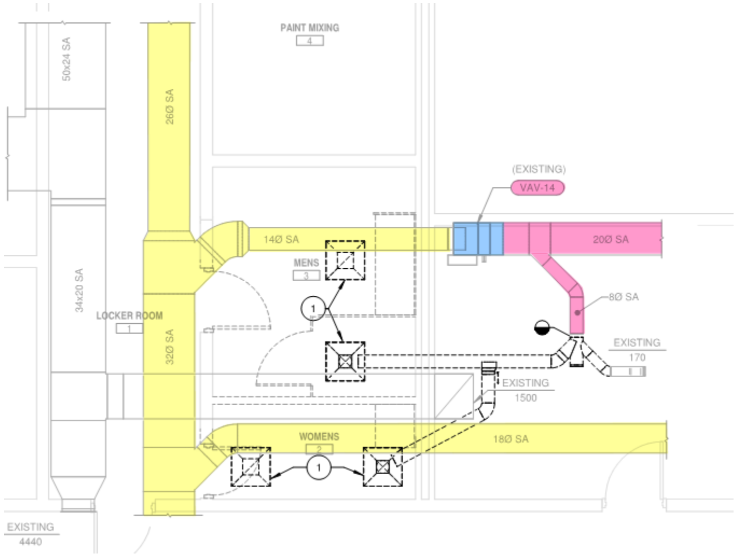


Pre-Engineering & Pre-Construction Measurements

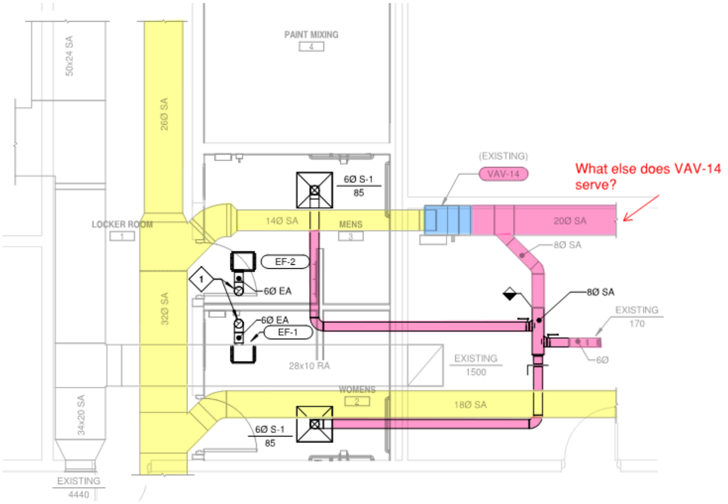
- Is there a difference? When should the measurements be taken? **Before design** or **before demolition**?
- What are you really looking for? Why are the measurements needed? After demo, does the data mean anything…the system changed.
- Can the data be obtained?
  - Pneumatic control system for a VAV system, is obtaining total AHU airflow possible? Establish a connected load. **Think system!!**
  - Occupancy?

Pre-Engineering & Pre-Construction Measurements

Demolition



New Construction

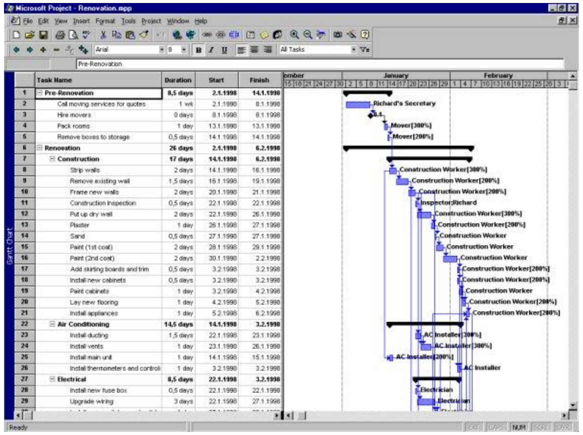


Scheduling Challenges

- There needs to be enough time allowed in the schedule for the TAB & Cx work to be completed. Request TAB durations early in the scheduling process.
- All work must be complete for TAB work to commence.
  - Clean air filters installed.
  - All strainers cleaned and start-up strainers removed.
  - All balancing dampers installed and 100% open.
  - All manual balancing valves and flow measuring stations installed and 100% open.
  - Temperature Controls complete and functional.

Scheduling Challenges

- Remember that TAB work is completed **by system, not by area**.
  - HVAC systems are typically "Vertical" and buildings are finished "horizontal"
  - Very seldom does the HVAC system match the "Phased or Scheduled Areas"
- Make sure that the Owner & Architect understand the possibility that the TAB work might be performed after occupancy.
- **Variable volume systems** (air and water) can have provisions to balance partial HVAC systems. Constant volume systems can pose scheduling complications if they overlap several areas/phases.
- Hydronic systems need to be carefully considered for scheduling issues.



TAB Reports

- Typically a final TAB report is NOT available at time of commencement of the Cx FPT's.
- Have an experienced, responsible engineer review the report. It is **not** just about **matching numbers**. It is **reviewing system performance** and employing engineering judgment.
- Don't hesitate to **call the TAB agency** to review the report together or ask questions.
- Keep in mind that **there is no benefit to the TAB Agency to report problems or deficiencies, it is a responsibility**. Be cautious of the **"pristine" TAB report**.

Questions?

Jim Hall, PE, TBE, CxA
Systems Management & Balancing, Inc.
925 SE Olson Drive
Waukee, IA 50263
515-987-2825
www.hvactab.com

System Design/Equipment Selection
Domestic & Lab Water Systems

- **Plumbing Pumps**
- **Fire Pumps**
- **Steam Condensate Pumps**

Typically these type of systems cannot be accurately tested without a constant, established water flow.

System Design/Equipment Selection
Domestic & Lab Water Systems

- A non-invasive procedure is recommended
  - Ultrasonic Flow Meter
  - Pipe surface temperature
  - Permanently installed gauges and/or thermometers
- A balancing valve is still required to allow for proportioning of the water system
- Consider installing temperature sensors on the domestic hot water recirculation loop that can report the temperatures to the DDC system

Shortridge Owner's Manual

1.0 SAFETY WARNINGS

READ ALL SAFETY WARNINGS CAREFULLY BEFORE USING HYDRODATA MULTIMETER.

Do **not** use the HydroData Multimeter or accessories on potable (drinkable) water or on any other fluid systems which may be used for human or animal consumption (or which may otherwise cause a health risk) because of the possibility of the system being tested becoming contaminated by residue from within the meter, piping or hoses.

The HydroData Multimeter and Valve Network Panel are designed for pressure measurement of **non-potable water** and **air** hydraulic and hydronic systems. This meter is not designed for and must not be used with potentially hazardous fluids or connected to any pressure source greater than 250 psi.

Do **not** use the HydroData Multimeter or Valve Network Panel to measure steam or high temperature hot water systems, or with acid, caustic, or any other hazardous chemicals.

Safety

Alnor Owner's Manual

! WARNING

- The HM 650 is intended for use on hydronic heating and cooling systems only. Never use the instrument on potable water systems or other systems which may be used to convey fluids or air for human or animal consumption.
- Never use the HM 650 to measure the pressure of volatile, flammable, or otherwise hazardous fluids or gases. The instrument is not designed to be intrinsically safe nor is it intended for use with caustic or corrosive chemicals.
- Never use the HM 650 on steam or temperatures greater than (100°C; 212°F) water.
- Always observe proper safety precautions and wear the appropriate personal protective equipment when working on high pressure systems. Ruptured
- Use caution as you release the water or air pressure when disconnecting the instrument to lessen the risk of water spray and personal injury.
- Exercise appropriate caution when using the HM 650 near electrical devices. Water spray when bleeding or disconnecting the high and low pressure lines poses a potential risk of severe personal injury and/or damage to equipment.
- Never connect the HM 650 to systems which exceed the instrument's maximum pressure specification (300 PSI; 2068 kPa).
- Always thoroughly drain and dry the HM 650's hoses and internal piping after use. This will help prevent accidental spills as well as the growth of hazardous microorganisms.

Water Flow Measurement: Pump Curves

Design Requirements:

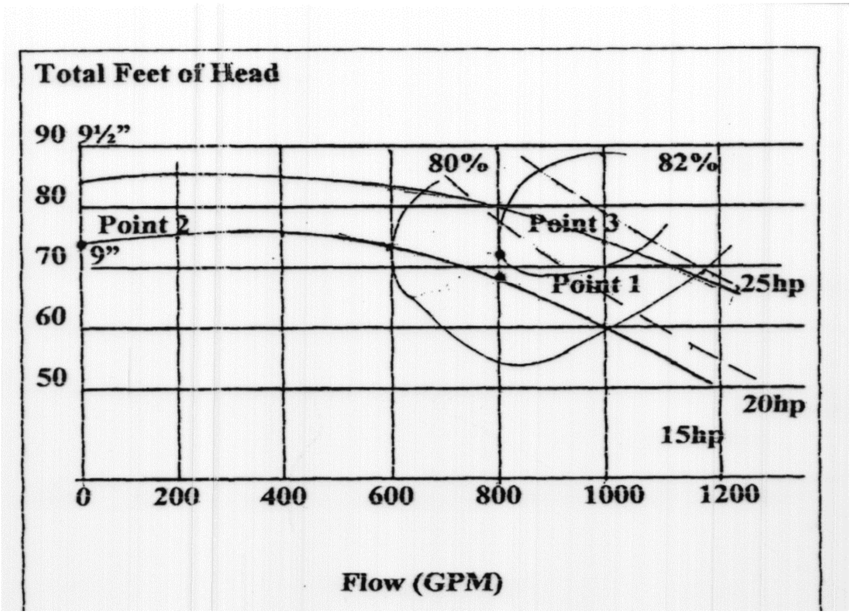
- 800 gpm @ 68'
  9" Impeller, 20 hp motor, 5BC,1750 rpm (Point 1)

Field Measurements:

- Shutoff ΔP = 73' (Point 2)
- Operating ΔP = 70.0'

Results:

- Actual: 700 gpm w/9" imp
- 12.5% below design
- Flat Pump Curve – Hard to interpolate.
- Utilize measured flows at terminals or branches to determine pump total.



Water Flow Measurement: Pump Curves

Design Requirements:

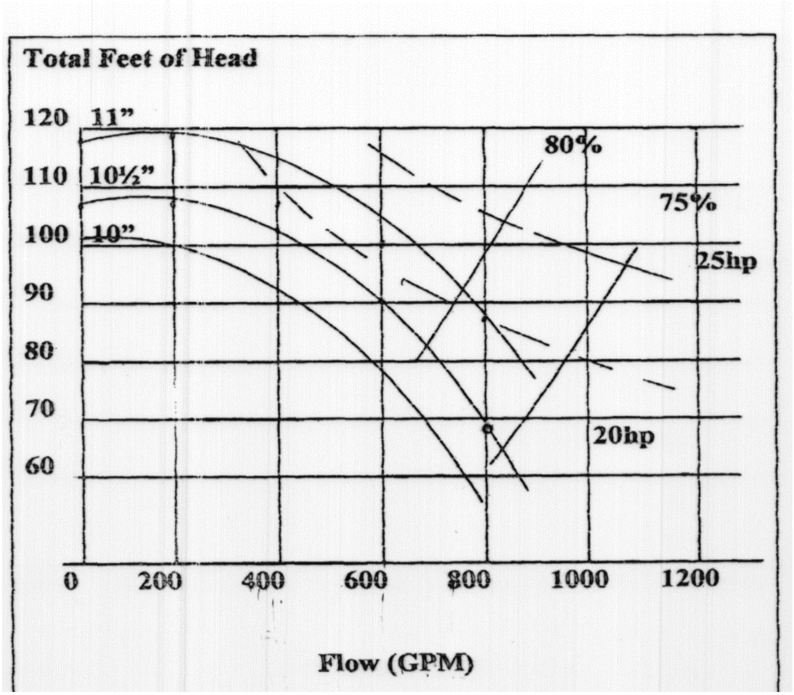
- 800 gpm@ 68’
  10-3/8” Impeller, 20 hp motor, 4E, 1750 rpm

Field Measurements:

- Shutoff ΔP = 104’
- Operating ΔP = 72’

Results:

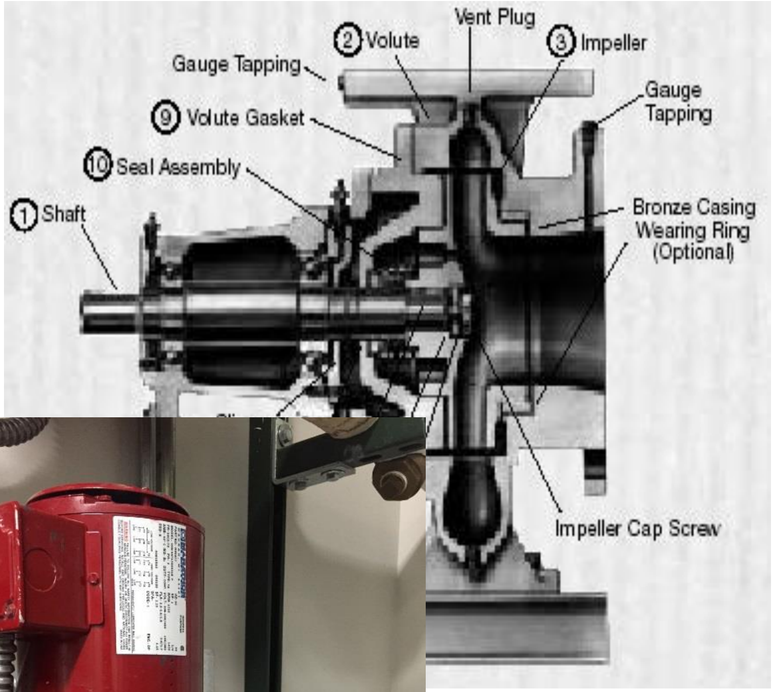
- Actual: 775 gpm w/10-3/8” imp
- 3.1% below design
- **Steep Pump Curve** – Immediate Resolution.



Pump Flow Measurement

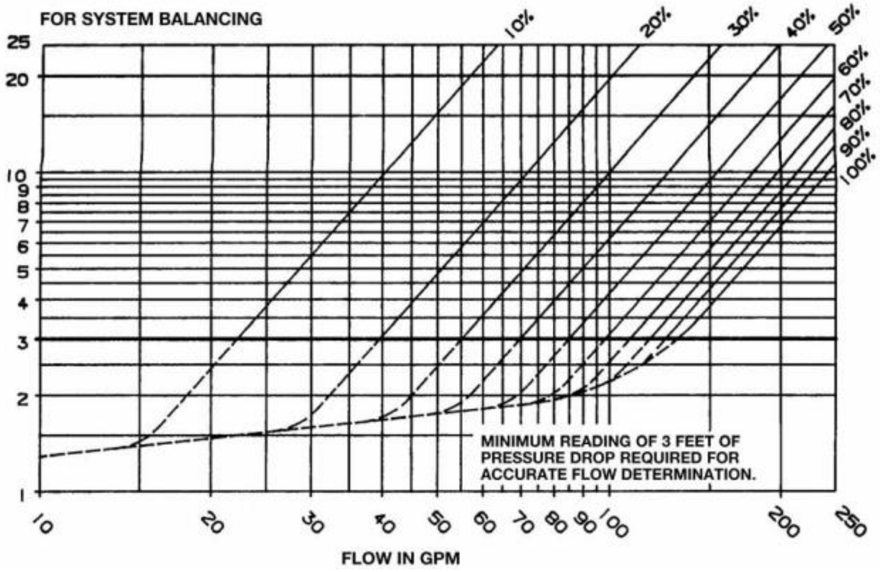
- Provide test ports/pump taps at the pumps (Extend outside of insulation).

- Provide a flow measuring device at the pump
  Fixed orifice type device preferred, use Multi-Purpose Valves with caution (sized properly).



Water Flow Measuring Stations: Sizing

- Flow measuring stations need to be sized to allow for a measurable and useful pressure drop.
  - Size the FS for water **flow quantity** and not **pipe size**
- The use of Multi-Purpose Valves for total pump flow measurement
  - Typically sized line size and not for flow quantity (oversized)
  - Location is not ideal, need 5 pipe diameters before and after the valve.



Water Flow Measuring Stations: Strainer Effect

¾" Balancing Valve 50% Open

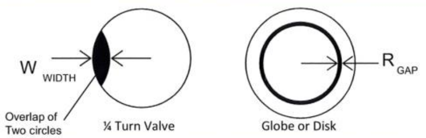
¾" Balancing Valve 25% Open

Water Flow Measuring Stations: Strainer Effect

PRO Hydronic Specialties

Physics Driven Solutions for Hydronic Balancing

Strainer Effect on Low Flow Globe Style Manual Valves

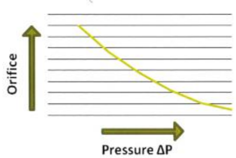


Pressure ΔP	Area In²	Max Gap ¼ Turn Valve	Max Gap Globe Style
2	0.0186	0.074	0.0108
5	0.0118	0.054	0.0085
10	0.0083	0.042	0.0072
20	0.0059	0.034	0.0060
30	0.0048	0.030	0.0054

All smaller than 10 mesh screen

1.0 GPM Flow - Calculated

Estimates of Area which vary depending on Coefficient of Discharge



For a Given Flow;

As the Pressure increases, the Orifice decreases.

Inversely, as the Orifice increases, the Pressure decreases.

General Relationship of Orifice/Pressure for a Given Flow

The calculations on this document are generalized due to the Flow Coefficient (K) being unknown and varying for diverse flow orifice conditions. While changes in K do effect the orifice size, these orifices are still very small for low flows. It is the purpose of this document to demonstrate that these orifices are often smaller than the strainer mesh openings, not to determine the exact size of the orifice for a given flow. The physical configuration of the gap from the Globe Design is smaller than the mesh opening for low flow requirements while a quarter turn valve allows for optimal orifice size for a manual balancing valve.

According to ASTM E 11-04 Specifications

Approximate Opening:
U.S. No 10 Test Sieve – 0.078"
U.S. No 20 Test Sieve – 0.033"

Equation to Determine Approximate Orifice for a Given Flow

$$A = \frac{Q}{25K\sqrt{\Delta P}}$$

Equation to Determine Max Gap using Disk or Globe Restriction

$$R_{GAP} = R - \sqrt{R^2 - \frac{A}{\pi}}$$

Q = Flow
A = Area
K = Flow Coefficient = 1
• P = Pressure Differential
R = Radius of Orifice

NOTE: Actual orifice dimensions will vary depending on the flow characteristic

Equation to Determine Center of Two Circles Given Known Area of Overlap

$$A = r^2\cos^{-1}\left(\frac{d^2+r^2-R^2}{2dr}\right) + r^2\cos^{-1}\left(\frac{d^2+R^2-r^2}{2dr}\right) - \frac{1}{2}\sqrt{(-d+r+R)(d+r-R)(d-r+R)(d+r+R)}$$

$$r = R = \text{Ball I.D.} = 0.5$$

Equation to Determine Width of Overlap $W_{WIDTH} = 2R-d$

2306 Sherwin Street
Garland, TX 75041

T: 972.271.8801
F: 972.271.8802

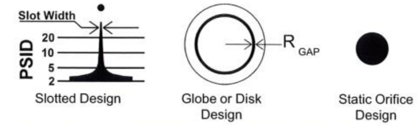
www.prohydronic.com
sales@prohydronic.com

PRO Hydronic Specialties

Physics Driven Solutions for Hydronic Balancing

Variable Orifice Strainer Effect Under Low Flow Conditions

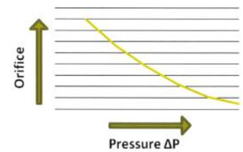
For a given differential, the slotted and globe design have the same area.



Pressure ΔP	Slot Width	Disk Gap (R-GAP)	Diameter of Static Orifice	Area In²
2	0.350	0.0108	0.165	0.0186
5	0.060	0.0085	0.165	0.0118
10	0.015	0.0072	0.165	0.0083
20	0.008	0.0060	0.165	0.0059
30	0.002	0.0054	0.165	0.0048

1.0 GPM Flow - Calculated

Estimates of Area which vary depending on Coefficient of Discharge



For a Given Flow;

As the Pressure increases, the Orifice decreases.

Inversely, as the Orifice increases, the Pressure decreases.

General Relationship of Orifice/Pressure for a Given Flow

The calculations on this document are generalized due to the Flow Coefficient (K) being unknown and varying for diverse flow orifice conditions. While changes in K do effect the orifice size, these orifices are still very small for low flows. It is the purpose of this document to demonstrate that these orifices are often smaller than the strainer mesh openings, not to determine the exact size of the orifice for a given flow. The physical configuration of a Slotted Orifice or the gap from the Globe Design is smaller than the mesh opening for low flow requirements. A Static Orifice Pressure Independent design allows for optimal orifice size for an automatic flow limiting valve.

WARNING: Cascade Failure Can Occur with a Variable Orifice Design!

Why? These are pressure dependent for position (P1, P2). As the orifice becomes clogged, the differential pressure increases resulting in the piston closing further with even smaller orifices that clog more quickly. Cascade failure is imminent with total stoppage of flow once clogging begins.

Equation to Determine Approximate Orifice for a Given Flow

$$A = \frac{Q}{25K\sqrt{\Delta P}}$$

Equation to Determine Max Gap using Disk or Globe Restriction

$$R_{GAP} = R - \sqrt{R^2 - \frac{A}{\pi}}$$

Q = Flow
A = Area
K = Flow Coefficient = 1
• P = Pressure Differential
R = Radius of Orifice

NOTE: Actual orifice dimensions will vary depending on the flow coefficient

Equation to Determine Gap / Width of Slotted Design

Taken from Actual Measurements

2306 Sherwin Street
Garland, TX 75041

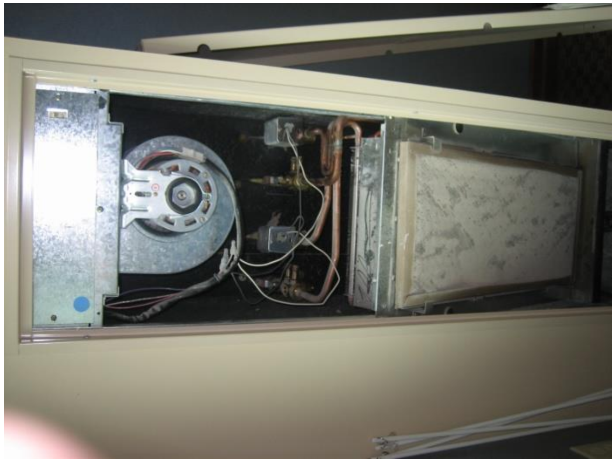
T: 972.271.8801
F: 972.271.8802

www.prohydronic.com
sales@prohydronic.com

Water Flow Measurement: Automatic Flow Limiting Devices

- These devices do not eliminate water balancing.
- Ideal for fan coil units, unit ventilators, heat pumps, VAV reheat coils and areas where access to valves is limited (actual pressure readings might not be obtained for each auto-flow).
- Factory-installed piping kits frequently do not provide access to the ports!!!
- Make sure they get installed in the correct locations, per GPM not just pipe size.

Water Flow Measurement: Factory-Piped Balancing Valves



This concludes The American Institute of Architects Continuing Education Systems Course

Jim Hall, PE, TBE, CxA

Systems Management & Balancing, Inc.

925 SE Olson Drive

Waukee, IA 50263

515-987-2825

www.hvactab.com