Balancing Ventilation Systems
An Annotated Bibliography

Mark J. Limb

2001

This report is part of the work of the IEA Energy Conservation in Buildings & Community Systems Programme.

Publication prepared by

Annex V Air Infiltration and Ventilation Centre

Document AIC-BIBLIOG-11-2001

ISBN 1 902177 21 4

Annex V Participating Countries:

Belgium, Denmark, Germany, Greece, Finland, France, Netherlands, New Zealand, Norway, Sweden, United Kingdom and the United States of America.

Preface

International Energy Agency

The International Energy Agency (IEA) was established in 1974 within the framework of the Organisation for Economic Co-operation and Development (OECD) to implement an International Energy Programme. A basic aim of the IEA is to foster co-operation among the twenty-four IEA Participating Countries to increase energy security through energy conservation, development of alternative energy sources and energy research development and demonstration (RD&D).

Energy Conservation in Buildings and Community Systems

The IEA sponsors research and development in a number of areas related to energy. In one of these areas, energy conservation in buildings, the IEA is sponsoring various exercises to predict more accurately the energy use of buildings, including comparison of existing computer programs, building monitoring, comparison of calculation methods, as well as air quality and studies of occupancy.

The Executive Committee

Overall control of the programme is maintained by an Executive Committee, which not only monitors existing projects but identifies new areas where collaborative effort may be beneficial.

To date the following have been initiated by the Executive Committee (completed projects are identified by *):

I	Load Energy Determination of Buildings*
II	Ekistics and Advanced Community Energy Systems*
III	Energy Conservation in Residential Buildings*
IV	Glasgow Commercial Building Monitoring*
V	Air Infiltration and Ventilation Centre
VI	Energy Systems and Design of Communities*
VII	Local Government Energy Planning*
VIII	Inhabitant Behaviour with Regard to Ventilation*
IX	Minimum Ventilation Rates*
X	Building HVAC Systems Simulation*
XI	Energy Auditing*
XII	Windows and Fenestration*
XIII	Energy Management in Hospitals*
XIV	Condensation*
XV	Energy Efficiency in Schools*
XVI	BEMS - 1: Energy Management Procedures*
XVII	BEMS - 2: Evaluation and Emulation Techniques*
XVIII	Demand Controlled Ventilating Systems*

XIX	Low Slope Roof Systems*
XX	Air Flow Patterns within Buildings*
XXI	Thermal Modelling*
XXII	Energy Efficient Communities*
XXIII	Multizone Air Flow Modelling (COMIS)*
XXIV	Heat Air and Moisture Transfer in Envelopes*
XXV	Real Time HEVAC Simulation*
XXVI	Energy Efficient Ventilation of Large Enclosures*
XXVII	Evaluation and Demonstration of Domestic Ventilation Systems
XXVIII	Low Energy Cooling Systems
XXIX	Daylight in Buildings
XXX	Bringing Simulation to Application
XXXI	Energy Related Environmental Impact of Buildings
XXXII	Integral Building Envelope Performance Assessment
XXXIII	Advanced Local Energy Planning
XXXIV	Computer-Aided Evaluation of HVAC System Performance
XXXV	Control Strategies for Hybrid Ventilation in New and Retrofitted Office Buildings (HYBVENT)
XXXVI	Retrofitting in Educational Buildings - Energy Concept Adviser for Technical Retrofit Measures
XXXVII	Low Exergy Systems for Heating and Cooling of Buildings
XXXVIII	Solar Sustainable Housing
XXXIX	High Performance Thermal Insulation Systems (HiPTI)
XXXX	Commissioning Building HVAC Systems for Improved Energy Performance

Annex V Air Infiltration and Ventilation Centre

The Air Infiltration and Ventilation Centre was established by the Executive Committee following unanimous agreement that more needed to be understood about the impact of air change on energy use and indoor air quality. The purpose of the Centre is to promote an understanding of the complex behaviour of air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.

The Participants in this task are Belgium, Denmark, Finland, France, Germany, Greece, Netherlands, New Zealand, Norway, Sweden, United Kingdom and the United States of America.

Contents **Page**

Other Bibliographies in this series:

(1). Ventilation and Infiltration Characteristics of Lift shafts and Stairwells,
(2). Garage Ventilation,
(3). Natural Ventilation,
(4). Air Intake Positioning to Avoid Contamination of Ventilation Air;
(5). Heat Pumps for Ventilation Exhaust Air Heat Recovery,
(6). Ventilation in Schools,
(7). Ventilation and Acoustics,
(8). Passive Cooing Technology for Office Buildings,
(9). Impact of Urban Air Pollution of the Indoor Environment,
(10) Cleaning Ventilation Air Ducts.

Scope

This bibliography is aimed at researchers, designers and engineers who are seeking an overview of current techniques, equipment and standards relating to HVAC system balancing. References quoted in this document are taken from the AIVC's bibliographic database, AIRBASE and, subject to copyright restrictions are available to organisations in AIVC participating countries, through the Centre's library service.

1.0 Introduction

In the ASHRAE HVAC Applications Handbook Chapter 36, a number of key terms are defined, for example **Test** *is the process of determining quantitative performance of equipment*, **Balance** *is the proportion flows within the distribution systems (sub mains, branches and terminals) according to specified design quantities.* **Adjust** *is the regulation of the specified fluid flow rate and air patterns at the terminal equipment (e.g. reduce fan speed, adjust a damper).* **Procedure** *is an approach to and execution of a sequence of work operations to yield repeatable results,* and **terminal** *is a point where the controlled medium enters of leaves the distribution system.* These may be variable air or constant air boxes, grilles, diffusers and hoods.

Good ductwork design and installation is key to providing well balanced ventilation systems. A number of fundamental handbooks exist that carefully outline he the essential elements of designing ventilation air ductwork. Organisations such as Chartered Institute of Building Services Engineers (CIBSE) and American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE) as well as individual authorities in the field such as Harrison and Gibbard (#13493, 1965), Brooks (#8676, 1995) and Chadderton (#7214, 1991) among many others. Brooks notes that using a fan and a series of conduits represents the most efficient way to move air around a building. This ductwork must allow the air to move as efficiently as possible so that operating costs are low, objectionable noise is prevented and duct heat gains and losses are minimised. The ductwork must also be able to withstand internal pressures and contain the air so that it is distributed to the proper locations. A fundamental design requirement is that the correct amount of air is supplied to the space to meet the necessary ventilation requirements. The fan and ductwork should therefore be sufficiently efficient and sized to overcome the forces of friction and pressures encountered so that the air supplied to specific spaces is the adequate. The air may be supplied through a number of vents within the space, in this case, the sum of the air supplied should meet the requirements. Brooks identifies duct design methods such as constant velocity, velocity reduction or equal friction methods. These are sizing methods where the diameter of the ductwork can be determined without calculating pressure drops. After the entire system is sized, it is analysed to determine the pressure drops and a critical path. Done manually, the longest leg is analysed and it is considered the critical path. The fan is selected to supply the pressure for the supposed critical path. After installation the, testing/adjusting/balancing (TAB) people attempt to balance the system.

The constant velocity method is usually used for exhaust systems conveying particles. All duct sizes are selected to maintain minimum carrying velocity. The velocity reduction method reduces velocity from high values at the fan to lower values near terminals where duct sizes would typically be smaller. The equal friction method sizes ductwork to maintain a constant friction loss per unit length of duct. Sizing with the equal friction methods is straightforward when a friction chart is available. If the layout of the duct is symmetrical with run-outs of approximately equal lengths, the equal friction method may produce a better balanced system than either the constant velocity or velocity reduction method. . However short runs will require much less pressure than long runs for the same friction rate. The selection of takeoff fittings and inline fittings such as elbows etc could have a strong influence on the selection's pressure losses and the system could be out of balance even if the lengths of duct runs are relatively constant.

The static regain method is more complex than the methods outlined above. The premise behind this method is to design balanced systems. For a given operating pressure balanced systems will generally cost less on an installed basis. However, this method does not lower operating costs, since, the initial conditions at the fan (such as the initial velocity or initial duct size) must be selected to begin the static regain method, it has a large number of solutions, like the other methods presented. The best static regain design is one that minimizes the total owning cost (first cost plus operating and maintenance costs) of the system. The underlying principle of this method is to size a duct run so that the increase in static pressure due to regain from velocity reduction at each branch or terminal just offsets the total pressure losses of the section being designed. Once any system has been sized it should be analysed using total pressure to determine if smaller sizes of less expensive fittings can be used in non-critical paths to reduce costs and further balance the system. The ASHRAE T-method of duct design aims to optimise systems considering equipment and operating costs. The basis of this system is minimisation of the objective function that represents the present worth owning and operating costs of the duct system. In the T method the duct system is considered a tree structure, the branches and roots of the tree are systematically condensed, resulting in a single imaginary duct section of resistance with identical hydraulic characteristics. This equation is minimised to cost and an optimised fan is selected. The system is then expanded to its original sections, distributing (optimised) total pressure as it expands.

Harrision and Gibbard (#13493, 1966) consider the main problem related to balancing an air duct system is that the alteration of the setting of any one damper in the system alters the rate of flow, not only in that branch which the damper controls, but also in all the other branches in the system. As a consequence, however great the skill and experience of the tester, it is very seldom possible to set any damper so as to achieve the correct absolute values of air flow, without several subsequent corrections. The result of any change however, can only be determined by measurement, so that a time consuming process is made even slower and more cumbersome by the need to measure the effect of each change. The author's alternative to this method is proportional balancing, which is outlined in section 2.

A number of authors have highlighted the problems of poorly balanced ventilations systems including Seppanen's (#12724, 1998), (#8369, 1994) (#9547, 1995) and Teijonsalo et al (#9901, 1996). A common inference is that imbalances of the outdoor airflows lead to high energy consumption in the rooms with high outdoor rates and deteriorated air quality in the rooms with low outdoor airflow rates. By balancing the airflows, the average air quality in a building can be improved and energy efficiency improved. Too low outdoor ventilation rates are also possible in VAV systems with no minimum supply airflow value. Poorly balanced ventilation will cause excessive airflows in some offices which are not economical and will most likely cause draughts. While people in offices with too low airflows all require more ventilation. Therefore more emphasis should be placed on the proper maintenance and operation of ventilation systems in general, and the balancing of airflows in particular.

Loyd (#10976, 1997) considers ventilation system balancing and re-balancing after duct cleaning has been undertaken. He outlines the critical factors affecting the balance of a ventilation system, including, correct fan adjustment (direction and speed), correct volume airflow must be provided by fans, all volume control dampers must be set correctly, all fire dampers must be set in the open position and be fully operational. Systems should be clean and free from obstructions. All filters should be correctly installed and in the correct range of operating cleanliness. Ductwork and air handling units (fan, coils and other components) should also be clean and the system should be free from any blockage in the ductwork. Rebalancing after cleaning may be necessary where the building use of system layout has changed. Before any rebalancing is carried out the system should be put back into operation and space conditions monitored.

2.0 The Proportional Method of Balancing Ventilation Systems

The ASHRAE Standard 111-1988 "Practices for measurement, testing adjusting and balancing of building heating ventilation air conditioning and refrigeration systems", outline the this procedure which aims to determine and compare the ratio of the measured flow to design flow for each outlet, branch ducts and sub-main ducts. The method is conducted as follows: Starting at the outlets, adjust the outlet damper for the outlet where the measured to design flow ratio is second lowest, until the ratio for this outlet equals that of the first outlet with the lowest ratio (Do not adjust the first outlet with lowest ratio of measured to deign flow). Measure the airflow to the outlet wit the lowest ratio again, and recalculate the ratio for this outlet. Readjust the outlet with the second lowest ratio again until these ratios are equal. Repeat on the outlet with the next lowest ratio and so on. Until all outlets on this branch have been adjusted to their proper proportion of airflow. Actual airflow of the lowest ratio outlet and subsequent balanced outlets will increase as each additional outlet is balanced. Once all outlets have been balanced according to this method, the proportioning of air to branch ducts is undertaken.

Set all thermostats for full cooling airflow on all branches of the sub main being balanced. Make sure space temperatures allow demand for full cooling. Determine the airflow through each branch duct off the sub main duct being tested. Starting at the far end of the sub main duct with the lowest measured to design flow, adjust all branch dampers until the ratio of measured to design flow for each branch on that main duct system is the same, always comparing to the first branch which is not adjusted. Beginning with the next sub main duct, with the lowset measured design flow, repeat the above steps.

Once these have been proportionally balanced, a Pitot tube traverse of all sub-main ducts is undertaken. Adjust all sub main dampers to proportion flow into each sub main duct such that the ratio of the measured to design airflow is the same of each sub main duct, always comparing to the first sub main which is not readjusted. Once all the ducts have been balanced in this way, perform a final check of airflows in each branch beginning with the sub main duct with the lowest measured to design flow. If the ratio for any branch of a sub main system is greater than 10% higher than the ratio of the lowest branch, the highest branch shall be adjusted until this tolerance (10%) is met. Repeat these operations for all sub-main ducts and adjust accordingly. Adjust the fan speed or volume control to obtain the total design airflow in the system, obtained by measuring by Pitot tube traverse of the main duct. Reset all controls for normal operations.

ASHRAE Standard 111-1988 also outlines the instruments required to carry out testing and balancing of HVAC systems.

The proportional methods has also been described and discussed by a number of other authors including Harrsion and Gibbard, Williams, and Loudermilk and Crowder. Harrision and Gibbard (#13493, 1966) suggest that to preserve the ratios, in spite of all subsequent alteration of other dampers, it is necessary to make each junction balance in its proper order. The authors examine the theoretical basis for this method, given that it depends on the validity of the assumption that at a given branch (tee or Y) fitting, the relative flow in each branch will remain unaltered, with changes of total flow in the main duct. The author examines the validity of this assumption and explains in some detail how proportional balancing is undertaken, and the accuracy and working limits likely to be expected of results concentrating of low velocity system but there is a brief discussion of how the method can be extended to high velocity induction systems.

The basic principles of balancing air circuits is also described by Williams (#2046, 1967). Based on the ratio of airflow rates delivered through each branch of duct in relation to each other remains constant when the total of air supply to them varies. It can be shown that in balancing an airflow circuit it is necessary; firstly to adjust the rate of airflow through branches in proportion to each other in accordance with the respective design rates of airflow; secondly to adjust the total rate of airflow to the design value. The second part of the paper by William describes a method of balancing of airflow circuits in low pressure ventilating systems. The method of balancing using pre-calibrated air volume dampers has been shown to be reliable and quick. Only two adjustments were required to bring the airflow circuits tested in the laboratory into balance. This method took only one quarter on the time required by a "Systematic Trial and Error" method in balancing an airflow circuit with four branches in the laboratory. The author outlines a 15 point plan for balancing the airflow.

1. Measure the rate of total airflow delivered by the fan.
2. Adjust the main balancing damper of the fan to give approximately the design rate of airflow ± 10%.
3. Measure the rate of airflow through each branch.
4. Calculate the ratio between the design rate of airflow and the actual rate of airflow for all branches.
5. Select the lowest ratio.
6. Divide the lowest ratio by the other ratios individually. This will give the proportion by which the rate of airflow must be reduced.
7. Enter the ratios calculated in 6, individually into the calibration curve. Read from the curve the damper knob setting required.
8. Adjust the damper knob settings accordingly.
9. Measure the rate of airflow through each branch, and calculate the ratio of actual to design rates for air flow as in points 3 and 4.
10. Divide the ratio, calculated in 9, of the branch selected in 5, by each of the other branch ratios, calculated in 9 in turn.
11. Multiply the new ratios from 10 by the respective figures of the damper knob settings obtained in 8.
12. Adjust the damper knob settings in accordance with the figures given in 11.
13. Check the rate of airflow after the second adjustments from 3 and 4. If the ratios for all branches do not differ by more than the percentage error of the flow meter proceed to. If not repeat 10 to 13 and repeat if necessary.
14. Adjust the main balancing damper of the fan to the design rate of airflow. (all branches should be now in balance, that is to say they deliver the rates of airflow required by the design).
15. Check the rate of airflow through each branch.

Where the main trunk from the fan supplies a number of sub trunks and each sub trunk in turn supplies a number of branches, the branches supplied by individual sub trunks can be proportionally balanced as 1 to 13 then the sub trunks can be treated as branches and balanced as 1 to 15. The author concludes that this system was tested both in the laboratory and in a real building, in both instances balancing was attained with ± 4%, which is within the range of the flow meter. The paper also describes the development of an averaging pressure tube flow meter for the measurement of airflow in ventilation ducts.

Loudermilk and Crowder (#13498, 1981) recognises the two most common balancing procedures are the proportional balance and traverse procedure. The Proportional balancing procedure involves:
1. Numbering the outlets, beginning with the farthest from the fan and working back
2. Starting with the farthest outlet from the fan, determining a ratio of the measured outlet velocity to the design outlet velocity.
3. Adjusting the second outlet until its ratio of measured outlet velocity to design outlet velocity is within a certain percentage of that of outlet number 1. This procedure is repeated for all outlets of that branch comparing this ratio to that of the outlet preceding it.
4. Repeat steps 2 and 3 for each branch.
5. Adjust branch dampers for the two branches that are farthest from the fan until the ratio of the measured velocity to the design velocity is equal.
6 Repeat step 5 for each branch, proceeding toward to fan.
7 After all balancing dampers have been adjusted, check the total airflow and adjust the fan speed to obtain the design total flow.

The CIBSE (1996) base their ventilation system balancing procedure on those outlined by Harrison and Gibbard (#13493, 1965) Which consists of working backwards to the fan from the remote branches, setting the correct proportional air flow at each junction of the system in turn (with regard for definitive flow rates) and so balancing the system. Once this has been completed the definitive air volume flow rates throughout the system are brought to their design values by adjusting the fan total volume flow rate. This system is adopted to avoid both cumulative errors and the need for test points and dampers in ducts between junctions. Adjusting the distribution dampers to obtain only a proportional balance has an important implication: the definitive values of rate of air flow in any part of the system do not need to be known at this stage. Hence the instrumentation used for measuring need not indicate the true value of air velocity . This means that inherent errors in the instrument that cause a consistently higher or lower velocity readings than the true value can be ignored. Also such as those for effective grille areas are usually self cancelling can be disregarded. The definitive value often system total air flow rate does not need to be established until the entire distribution system has been proportionally balanced. While carrying out a proportional balance of a system it is advisable to maintain the balanced section of the system at between 70% and 130% of the true design flow rate. If a system is balanced outside these limits the proportional balance may be impaired when the system total flow rate is adjusted to the design value.

Parsloe (1998) notes that the principle design aim is that the selection of ductwork, components, configurations and layouts which will ensure that the system is as inherently stable and self balancing as possible. The self balancing characteristics of the ductwork distribution system may be improved by considering the following design options:
1. The sizing of ducts, where appropriate by the principle of static regain. This method will help to ensure that approximately the same static pressure exists at the entrance to each terminal branch therefore simplifying the balancing procedure.
2. The selection of duct sizes to roughly balance the pressure drops across sub branches or terminal branches.
3. The avoidance of terminals with different characteristics on the same run. For example veiling diffuses and side wall grilles, or ceiling diffuses and combined air/lighting fittings. If the mixing of such terminals is unavoidable , provision must be made for in duct measurement on the sub branches.
4. The use of stub ducts to connect terminals to a main or principal branch duct. If direct connection cannot be avoided , turning vanes should be incorporated.

5. The avoidance of splitter dampers to divide flow - these will complicate the balancing procedure.

The UK BSRIA preferred balancing procedure is the proportional method. This method is outlined at length. However they state that successful application of the technique is dependant upon the inclusion of sufficient regulating devices suitably positioned in the ductwork installation. The balancing procedure outlined assumes that such devices have been installed in the ductwork branches to every terminal.

3.0 The Traverse Method of Balancing Ventilation Systems

Te traverse method, which requires a Pitot tube velocity traverse of each sub-main ducts to determine flow rate through each and adjustments to the main volume control dampers, to provide the required flow through each sub-main air duct is also described in AHRAE 111-1988 “Practices for measurement, testing adjusting and balancing of building heating ventilation air conditioning and refrigeration systems”.

Beginning with the sub main duct closest to the fan, a Pitot tube velocity traverses of each branch on that sub-main duct run should be undertaken. Proceeding from the branch with the highest percentage of required flow, adjust the branch volume control dampers to provide the required flow through each branch duct. Proceed to the sub-main duct with the next highest percentage of required flow, traverse and adjust each damper, continue until all braches are balanced. After each sub main and branch ducts and balanced then proceed to balance each air terminal. Beginning with the branch nearest the fan or with the highest percentage of required flow, measure the airflow at each terminal of the branch. Starting with the air terminal with the highest percentage of design flow adjust the run out or terminal volume control damper to provide an airflow rate with 10% of design. Repeat for all terminals connected to the branch. Then repeat the whole processes on the branch with the next highest airflow requirement. Once all terminals have been balanced to within 10% of design the final adjusting and balancing can be undertaken. Measure and record the final airflow rates at each terminal, adjust as necessary. Secure, mark, seal and record the final setting positions of all volume control dampers installed in sub-main and branch ducts. Finally Reset all controls for normal operations.

Loudermilk and Crowder (#13498, 1981) also outline the traverse procedure, as follows:

1. Starting the terminal balance from the fan out. The branch dampers should be used for major adjusting, terminal dampers for trim or minor adjustments only. On occasion, it may be necessary to install sub-branch dampers to decrease the use of terminal dampers, which may be creating objectionable noise.
2 Normally, several passes through the entire system are necessary to obtain proper outlet values.
3. Totalling the tested outlet air quality acts as a check of duct leakage when compared to required outlet air quality total.
4. With total air established in the branches and at the outlets, perform the following (a) take new amperage readings (b) find static pressure across the fan and (c) read and record static pressure across each component (intake, filters, coils, mixing dampers etc).

Loudermilk and Crowder note that this provides a standardised methodology for testing and balancing, however, the majority of the balancing procedure is based on a trial and error process of adjusting dampers until the system is tuned. Few attempts have been made to balance systems by placing dampers in positions determined by calculation prior to start up, partly due to lack of test data predicting the pressure loss characteristics of various devices which would be used in such a technique. The authors note that several methods of design ductwork specifically to end up with a balanced system have been devised, the balanced duct method and the blast gate method are two such examples. In the balanced duct method, duct sizes are chosen so that the static pressure balance at each junction will achieve the desired air volume in each branch duct. In the blast gate method calculations are undertaken, being at the branch of greatest resistance, subsequent branches are then sized to give the minimum required velocity at the desired volume. Blast gates are provided in each branch and after construction the gates are adjusted to give the desired volume. Other methods outlined by the author include Equal friction, velocity, reduction, static regain and constant velocity methods. Although the author expands his discussion around the total pressure design method, which is adopted from the static regain method. This method consists of a damper controlling airflow by altering the resistance of the duct system in which it is installed. In low pressure systems opposed blade and parallel leaf dampers are suitable, whilst in higher pressure systems, slide gate and blast gate dampers have achieved common use in the balancing of these systems. The authors suggest a method for balancing the ventilation system using a design incorporating slide gate dampers. Similar to the orifice plate procedure, used for balancing systems, where each take off from the main duct is situated a orifice plate into the branch duct. This orifice would be sized such that the pressure loss of the flow over the edge of this orifice would equal to that needed to balance the resistance in this branch to the resistance of the main duct at the point of take – off.

Loudermilk and Crowder also note that provided that the limitations of the technique are understood, ventilation and air distribution systems can be balanced during design using slide gates opposed of parallel blade dampers of centred orifices. The authors present data relating pressure loss to approach duct velocity pressure have been formulated which allow the application of slide gate dampers to such a technique. Some of the limitations include: placing slide gate dampers at least 2-4 equivalent diameter away from a branch take off. Extractors or turning vanes should be provided to insure that the air “fills” the duct prior to encountering the slide gate. Slide gate damper installation near diffusers is not recommended due to the effect on the flow profile. Finally access to the slide gate damper must be provided. In conclusion the authors note that the use of total pressure design method eliminates any possibility of the disregard of a pressure loss that can occur as pressures convert frequently from static pressures to velocity pressures due to the variation in flow cross section through the system.

4. 0 Alternative Approaches to Balancing Ventilation Systems

The expansion of computer power and availability has given rise to a new series of tools and advances in technology that has been harnessed by the TAB industry. These developments have been aimed at helping the TAB engineer and not removing his role. Examples are highlighted below.

Milewski (#13497, 1994) discusses the limitations of the emergence of the Direct Digital Controller (DDC) as an integrated device that can be used to aid the balancing of ventilation systems. Although all the main adjustments, maximum and minimum flows, heating flows, day and night set points, heating steps etc can be set at a remote location and restrictions do exist for adjustment at a particular zone without specialised equipment, the balancer still has the final word. Despite having to invest in and learn about new technology, the balancer can still decide on how much air is coming out of the diffuser. Multiple diffuser in a single terminal are not even addressed by the DDC system, and their balance work is completely unaffected by the DDC invasion. A weak link in this system is the terminal flow sensor’s accuracy. Therefore, despite the technological advances the only repeatable, calibrated, certifiable air flow information to the zone is that from the balancers equipment. Even basic things such as a forgotten diffuser connection or an open unused outlet, would only be identified by the balancer during his checkout. The authors also suggests that the basic principle of multi point sensing is flawed, producing in-situ errors that can be detected and corrected by on site independent confirmation. If, for example a piece of flexible duct is distorted out of shape, causing an increase in flow towards the centre of the ducting, the terminal pick up, even a multipoint averaging type doesn't have any pickup points within 12mm of the duct wall, so it only reads the higher velocity, which indicates a higher than actual air flow rate. The author concludes that there is only one solution to the problem of obtaining accurate settings on air terminals, and it lies with the balancer. Fortunately, the above mentioned mechanical errors, together with flawed averaging pickup, become constant after installation. So the solution is the balancer of DDC controls person drives the terminals to some temporary maximum. The balancer hoods the diffuser and establishes an accurate flow rate figure. The DDC installer then compares that flow figure to his flow reading factor needed with each terminal having its own in-situ factor. Since the flow will still follow a square root formula a custom flow curve for each terminal can be produced.

Pekkinen et al (#10045, 1996) also describes an intelligent control system that checks the ductwork and makes an automatic balancing procedure to determine the pressure drops of different ductwork components and branches. The approach outlined here is a departure from the traditional VAV system control strategy, in that it is based on knowing the ductwork geometry and calibrating the ductwork so that the intelligent control system knows the characteristics and can control the system according to needs. Thus all measurements in the normal operation are unnecessary. The system consists of software and a number of physical components. The software knows the geometry and the pressure losses of the ductwork. The control can be determined by a thermostat as in traditional VAV systems, or by a CO_2, humidity and/or occupant sensor can be used. The ductwork is described in the form of a table, which includes the number of the component, and to which others it is attached and the flow resistance coefficient. There are two types of components, ones with a fixed pressure drop (bends etc) and ones with variable pressure drop coefficient, like dampers. The authors note that pressure drops for different components can be found either during the commissioning phase, where the air flow rates and pressure drops can be measured manually, or by using the auto calibration feature, which means that the airflow management system itself has some measurement possibilities. The system is controlled by the software, because the software knows the geometry of the duct work and the pressure drop coefficients of the components. It also knows how much air is needed for each room. Thus it calculates the correct opening position for each damper in order that each room gets all of the air flow it requires. Every time the room controller (thermostat) is altered, the software calculates new operation positions for all dampers and they are corrected. The system can also be operated as a dynamic ventilation system, changing ventilation rates according to breaks for example. This air flow management system can always operate with minimum pressure level needed which saves electric energy of the fans and cooling system.

Larsen (#7726,1994) (#9830, 1996) examines recent improvements in electronics and computer technology it is now possible to do both the calculations and the balancing in a cost effective way. Personal computers have become a common tool for most engineers, a large variety of computer programs exist for calculating pressure losses. The author notes that test have shown that calculated results from reputable programs differ very little from actual measurements. The availability of reliable electronic pressure cells makes it simple to measure low air pressures in ventilation systems. Readings are easily presented on a display or as an analogue electrical signal. Finally dampers and air terminals are frequently equipped with differential pressure devices for measuring the air flow. The author outlines a new method for balancing ventilation systems called “dual pressure measurements” (DPM) method. It requires the pressure loss calculations have been made with a reliable computer program. Such programs will be able to determine the optimum pressure loss line for the whole system and over individual components. By adjusting air terminals and dampers to match the pressure loss line, a system can be brought into balance even when the airflow is far off from the required value. The differential pressures for both the air flow measuring device and the flow resistance are measured simultaneously. When adjusting the air flow through the air terminal or damper the two pressure differences are measured continuously (1-2 times per second) by the computer program, this in-turn calculates the k-value of the immediate pressure loss lone and compares it with the desired k-value. When the correct k-value has been reached the PC produces a high pitch sound. Therefore the damper and air terminal have been adjusted without having to bother about the magnitude of the air flow. Test have shown that the adjustments may be made as long as the air flow is not lower than approximately 30% of the nominal air flow. Below this linear flow may develop. Using this method it is possible to undertake balancing before the ventilation system is completed. For example, it is possible to balance a floor by hooking up a transportable fan to the ducts system of that floor. The author suggests that for many types of air terminals, especially exhaust air, a DPM machine is more practicable. This machine consists of a small fan, a device for measuring the air flow, two electronic pressure cells, a PC with an A/D-card installed and some pieces of ductwork. With some exercise it is quite common to adjust an air terminal to the required pressure characteristics in approximately 30 seconds.

Paschal and Hammersley (#13501, 1987) outlines an integrated description method of a buildings HVAC system, that may be used to support system testing and balancing, system performance analysis, capacity verification testing and room interactions. The method outlines a series of tools for system modelling, analysis and simulation developed from actual field experience gained during the balancing and star-up of HVAC systems at six nuclear units. The present discussion will focus on the system balancing tools and elements. Regarding balancing the author, states that ventilation system balancing is typically accomplished by an iterative trail and error procedure, which involves testing the system, adjusting the system’s balancing devices and then re-adjusting until the desired conditions are obtained. The number of iterations required to balance a system, however can be significantly reduced by employing a method of integrated system analysis. This method computerises the iterations, minimizing the time spent in the field on readjustments. Once the system resistances are determined and fan performance accounted for effects of various component combinations can be determined without further testing. An integrated model can be scaled to each selected application. Models can be constructed and applied to a single or subsystem, such as a control room zone airflow study, or to a group of several interrelated systems such as a building ventilation system study for nuclear plant containment. In the development of the model, the authors attempted to provide a baseline for comparative analysis and for repeatability of evaluated results, a comprehensive testing and balancing evaluation procedure was developed, based upon the AMCS fan application manual. This procedure allows for the base lining of actual airflow rate date and an indication of actual fan performance. Once the actual airflow rates and pressures are determined, the actual resistance of the duct system elements are calculated. These resistances are used as input to a mainframe nod-path computer code, which analyses performance of the system and determines the adjustments necessary. The authors by stating that amongst the various advantages of this system, its straightforwardness, and ease of use make it widely useable. It is also very versatile in handling different operating modes. A single model provides the ability to assess a variety of different problems. Finally this technique can be used to simulate system performance for both design and diagnostic purposes, it has outage or modified planning advantages analogous to those of physical modes. It also allows the comparative assessment of potential corrective actions in an integrated framework, which provides a systematic and reproducible means for identifying problems before they are realised in the plant.

Svensson (#7985,1994) outlines the development of a self acting pressure regulator which makes it possible to design more flexible systems. He regulator makes it possible for a constant pressure to be maintained in different branches of the ventilation system. The author attempts to address the question of whether there are any easy ways of making ventilation systems more flexible. One technically simple and god solution is to maintain constant static pressure at strategic points in a distribution network by means of constant pressure regulators described in this paper. It is then possible to vary the air downstream of the constant pressure regulator with a simple damper, controlled either manually or connected to a timer. These devices can maintain pressures from a few Pascal up to 200 Pa. The author suggests that these regulators can be installed into constant air volume, variable air volume and demand controlled systems, to aid commissioning and balancing.

Hanchi et al (#9679, 1996) considers optimal control of duct pressure in HVAC systems, principally variable air volume systems. VAV systems cost less to install than other alternative systems and are relatively effective in reducing the overall cost of building operations. Basically, a duct pressure control loop maintains the minimum value of static pressure in the duct system to support proper air distribution into the occupied space. In many VAV systems the supply air is maintained at a specific duct pressure by modulating fan output. Fan output can be modulated by either changing the fan speed or by changing the flow with a damper or a vane. Through modulating the damper the ATU changes the air volume flow rate to provide only enough conditioned air at a specified temperature to meet the load demands of the occupied space. In many VAV systems the duct pressure is maintained at a specific set-point by modulating the fan speed. The open loop transient response of pressure to the fan speed is important for the design of a pressure controller. Proper control of pressure requires having complete information on the transient and steady state response of pressure in the system. The pressure model is based on the measurements of input or the control signal to fan speed and the output or duct pressure. The energy consumed by the supply fan is a significant portion of energy consumed by an HVAC system. The fan is controlled to maintain a specific duct pressure within the system. This pressure is important for the operation of the ATU since the ATU airflow control depends on the pressure produced by the fan. To control the fan speed to maintain the desired duct pressure while minimising energy consumption, the power performance characteristics of the fan must be known. The authors then proceed to outline equations to determine the optimal control law of pressure within a duct. The performance criterion used was the energy consumed by the air supply fan for the system to achieve a desired pressure set-point. The system performance with the optimal control strategy was compared with adaptive and PI control.

Oughton et al (#4870, 1991) highlights the importance of commissioning and within this remit balancing of ventilation systems. The author states that many variable air volume systems, are self regulating. However they may indeed be so, once the system is operating under normal steady state conditions, however under start up the whole automatic control system is likely to be calling for full flow rates. Under these conditions balanced flow is vital if the acclimatisation (warm-up or cool down) is to be even throughout the system. Sizing of the distribution network is generally arranged to provide a measure of self balancing but limitations o pipe of duct sizes restrict the scope for this. Installation and accuracy of the design can also play important roles on the self balancing properties of the system. Accepting that self balancing therefore may not be effective, what would be the best procedure for flow balancing in such a VAV system. Where the design diversity used is common for al areas served by the system, normal proportional balancing principles can be applied. Where the design diversity differs from zone to zone then pro rata proportional balancing should be arranged. The author refers to the correct BSRIA TM Procedure for commissioning VAV air systems and BSRIA Air System Balancing

– Regulating Variable Flow Rates System for more information.

Riffat (#5690, 1992) and Cheong and Riffat (#7468, 1994) report on new equipment which could be used to balance HVAC systems. Using the constant-injection tracer gas technique it is described by the author as simple and quick to use, can measure airflow rates in HVAC systems directly and does not require determination of the cross sectional areas of ducts or velocity profiles. It can provide accurate measurement of airflow over a wide range of air velocities and can be used to measure airflow in ducts of different sizes, shapes and lengths and does not require a long measuring duct for the establishment of fully developed flow. The authors compare the new method with that established by the UK Chartered Institute of Building Services Engineers (CIBSE) which consists of working back towards the fan from the remote branches by setting the correct "proportional" airflow at each junction of the HVAC system without regard to absolute values of airflow. Once the HVAC system is balanced so that all parts of the system are carrying the same "proportion" of their design airflow, the fan speed or main damper may be adjusted so that the main feed duct carries 100% of its design. The proposed tracer gas method uses the constant injection technique to estimate and adjust airflow rates in the HVAC system. Tracer gas (SF_6) is injected into a duct at a constant rate, and the resulting concentration is measured. Assumptions are that the air and tracer gas are perfectly mixed within the duct, and the concentration of tracer gas in the outside air is zero. The procedure is outlined at length by the author, but essentially involves determining the percentage of design air flow required at specific terminals, and therefore the target concentration of tracer gas and by altering the damper settings or fan speed so that all diffusers carry 100% of design airflow, the system is the completely balanced. The tracer gas injection unit incorporates solenoid valves, a manifold, a mass flow controller, a switch controller and a tracer gas cylinder. The injection rate was controlled using a variable power supply and the rate of tracer gas injection was displayed on a digital unit. The tracer gas sampling system consisted of solenoid valves, a manifold, a switch controller and a gas analyser. The system was tested on a small scale HVAC system. Airflow rates were measured using a Pitot tube and compared with the tracer gas measurements. The difference between the two airflow rates was between 0-10%. Difficulties in measuring airflow at low velocities (below 3 m/s) using a Pitot tube produced large errors. The tracer gas equipment was found to be a simple and convenient method of measuring and balancing airflow in the HVAC system. The system could be balanced to a high degree of accuracy in a short period.

Ward (#7062, 1993) adapts the use of thermography to balance the air flow rates in a ventilation system. From finite difference analysis of the air transfer grille, it can be seen than the surface temperature is a function of the velocity of the air passing over it, and therefore it should be possible to determine the air velocity from a knowledge of the surface temperature history. Ward examines the use of this technique for a specific grille by using a hand held Infra-Red thermometer to measure the surface temperature of the grille when the heating systems was turned on over time. The predicted air flow rate of 2.5m/s compared well with measured rates of 2.3 to 2.5m/s prior to the test. To apply this procedure to the balancing of the whole ventilation system, several of grilles have to be tested. The first series of tests were to establish whether the variation in the surface temperature of a specific grille was a function of the air velocity and the heat input to the system. Results indicate that the heat input to the system was increased the surface temperature also increased. The air velocity also had an effect on the final conditions. The next series of tests were to establish if there were significant differences between various grilles. Results indicated that each grille has its own characteristics. However the differences are small and could easily be an overlap in practice. At higher volume flow rates the differences disappear and all the grilles appear the same. The next stage was to establish if the ventilation system could be balanced using the IR systems and the results of the calibrated grilles. The ventilation system was first set up using conventional balancing techniques. IR measurements were used to confirm the temperature/time history of the index grille. The system was then put out of balance, by altering a damper. The IR test was then applied. Although the tests were not absolute, there was a difference between the before and after results, although the tests did not show immediate balancing, the author notes that they are nevertheless optimistic. The test carried out have indicated that the temperature/time history of a ventilation grille may be used to establish if the ventilation system has gone out of balance. However further work is needed to quantify and prove how the IR system can be used for rebalancing.

Proskiw et al (#3386, 1988) outlines a Canadian study in which tracer gas tests and system balancing were undertaken in a number of houses to determine their performance under actual operating conditions. Protocols varied depending upon system, but basically consisted of measuring branch and main duct flow rates in the system and then making the necessary adjustments to achieve the design flow rates. In the case of forced air heating systems, only the total supply and exhaust rates were measured and adjusted. Branch duct air flows were measured at the appropriate supply or exhaust grille by traversing the face of the grille with a heated probe anemometer. Average grille face velocities were then multiplied by the grille free area to estimate the total air flow rate. Main duct flow rates were measured using the permanently installed flow measuring stations. The authors noted that for combined HRV/Forced air heating systems system balancing using the method outlined above took 3 hours. This included the completion of a written report on the system. The authors estimate that with a low resistance flow hood which could be used to more rapidly measure grille air flow rates this could be reduced to 1 to 2 hours. A similar amount of time was required to balance a dedicated HRV ventilation system.

Ghete and Nathwani (#9785, 1996) outlines the evaluation and rectification of the air distribution system for the Opera Theatre and Concert Hall at the Sydney Opera House. The system consists of constant volume air conditioners (3 for concert hall and 4 for Opera theatre), which supply from above and return back through slots located under the seats. Previously this system is provided with balancing dampers and air flow pattern adjusting devices on the supply side, the natural approach to control the air distribution was to adjust the supply air stream. Smoke tests were carried out to identify the supply distribution problems. These test indicated an uneven air distribution and incorrect air flow patterns, which results in the encountered problems. Radical changes were not considered, only improvements that preserved the existing arrangement were considered. The idea behind the proposed changes were to force the supply air to distribute in the return air system, instead of just attempting to balance the supply air. The air flow pattern of supply outlets required adjustments to obtain maximum Coanda effect, and after minimising of velocity pressure the few existing balancing dampers in return air ductwork and additional means were used to evenly distribute the air at seating level. Return air measurements were used as the basis for balancing of the return air. Huge variation in return air quantities were found ranging from practically no air to above 31 l/s per seat. The return air slots under the seats were partially blanked off, this enable the static pressure variation to be stablised by controlling the return air dampers through a differential pressure controller. As a result of rectifications carried out a balance accuracy of 20% all over the hall was achieved, by the partial blanking off return air slots. The accurate balance of return air in combination with high level of stability in operation of conditioners has ensured a far superior level of comfort for patrons at all outside temperature conditions and levels of occupancy. Following this investigation, the authors conclude that the achievement of correct air distribution in large halls, supplied with conditioned air from above and returned below is a difficult task and generally cannot be achieved by adjusting the supply only. The return air system has to be utilised to do part of the work, therefore returning air balancing provisions, (equal to the number of seats) is recommended for new installations). The authors suggest that the most apt system for such large auditoriums is one that supplies air from under the floor and it is provide with appropriate balancing means on supply air distribution.

5.0 Methods and Equipment

According to ASHRAE HVAC Applications Handbook Chapter 36, Testing, adjusting and balancing are fundamental design functions with most of the devices required for adjustments being integral parts of the design and installation. To ensure that proper balance can be achieved, the design engineer should show and specify a sufficient number of dampers, valves, flow measuring locations and flow balancing devices, which must be properly located in required straight lengths of duct for accurate measurement. Balancing tolerances of about ± 10% for indicial terminals and branches in non critical ducts and ±5% for main ducts should be specified.

The ASHRAE Handbook further states that The Pitot tube traverse is the generally accepted method of measuring airflow in ducts. Other methods of measuring airflow at individual terminals may be described by terminal manufacturers. Air diffuser manufacturers usually base their volumetric test measurements on a deflecting vane anemometer. The velocity is multiplied by an empirical effective area to obtain the air diffuser's delivery. Accurate results are obtained by measuring at the vena contracta with the probe of the deflecting vane anemometer. Measuring airflow of troffer-type terminals are simular to the methods for air terminals. The capture hood is frequently used to measure device airflows, primarily of diffusers and slots. Loss coefficients should be established for hood measurements with varying flow and deflection settings. If the air does not fill the measurement grid, the readings will require a correction factor (simular to the loss coefficient). Rotating vane anemometers are commonly used to measure air flow from sidewall grilles. Effective areas (loss coefficients) should be established with the face dampers fully open and deflection set uniformly on all grilles. Correction factors are required when measuring airflow in open ducts, i.e. damper openings and fume hoods. All flow measuring instruments should be verified by running Pitot-tube traverses to establish correction and /or density factors.

Most TAB air handling systems rely on measuring volumes in the ducts rather that at the terminals. These measurements are more reliable than those obtained at the terminals, which are based on manufacturers data. The preferred method of duct volumetric flow measurement is the Pitot tube traverse average. Although care should be taken to obtain the maximum straight run before and after the traverse station. When factory fabricated volume measuring stations are used, the measurements should be checked against a Pitot tube traverse. The power input to a fans driver should only be used as a guide to indicate its delivery. It may be used to verify performance determined by a reliable method considering system effects may be present. The flow rate from some fans is not proportional to the power needed to drive them. Where there is inadequate straight length of ductwork, or no ductwork to allow a Pitot tube traverse, a vane anemometer is used to read air velocities at multiple points across the face of a coil to determine a loss coefficient. In mixing plenums where the outdoor and return air are so thoroughly mixed as to render impossible an accurate determination of the relative air quantities then the temperature of the mixture can be used to indicate the balance between relevant air streams.

Air pressure measurement should include, barometric pressure, static pressure, velocity pressure, total pressure and differential pressure. ASHRAE Standard 111recommends how field evaluation of air handling performance pressure should be conducted. Pressure drops through cold, dampers or filters etc should not be used to measure airflow. The remaining of ASHRAE Handbook section 36, outlines instruments and procedures for testing and balancing HVAC systems. Then variable air volume systems are given special attention, due to the self regulating nature of these systems. It is noted that whilst they may be self regulating, they are not self balancing.

In a design and installation manual for residential mechanical ventilation systems published by the Alaska Craftsman Home Program (#12420) construction details to reduce energy consumption and moisture damage to dwellings in Alaska are outlined. The manual also provides details of the use of TAB instruments, including U-tube manometer, Vertical inclined manometer, electronic micrometer, Pitot tube, pressure gauge (magnehelic), anemometer (rotating vane and deflecting vane) and flow measuring hood. Their relative recommended uses and limitations are also given.

Parsloe (1998) also outlines the various measurement equipment used to adequately test and balance the ventilation system. The UK BSRIA's preferred balancing procedure is the proportional method. This method is outlined at length. However they state that successful application of the technique is dependant upon the inclusion of sufficient regulating devices suitably positioned in the ductwork installation. The balancing procedure outlined assumes that such devices have been installed in the ductwork branches to every terminal.

The systematic and random errors air airflow instrumentation used in field balancing are examined by Foltz (#13507, 1984). Six instruments were tested, a rotating vane anemometer, Deflecting vane anemometer (swing vane, bridled vane with and without scoop), a collector with variable airflow meter and a hot wire anemometer. The criteria for their selection was portability, accuracy and availability. The authors describes each instrument and then how it was calibrated and tested. The over riding conclusion was that apart from each diffuser requiring its own fitting correction factor, and that the average random error is the best overall indicator of an instruments suitability for a particular application. Results show that the random error was generally independent of the geometry and type of diffuser and the duct entrance geometry. The magnitude of the percent average random error for diffusers, calculated on the instruments full scales varied fro, 0.4% to 2.7%. However fro velocity ranges 2 to 4 m/s for diffusers it makes a considerable difference as to the instruments scale ranges. The random errors for all instruments were smaller when applied to the screened outlet. Possibly due to the higher velocities experienced with screened outlet as compared to the diffuses and a more constant velocity profile. The author concludes that from these experiments it can be deduced that proper correction factors should be used in balancing work, and should be determined either from literature or by test. Potential errors as large as –22% or +156%, have been demonstrated in this paper, if no correction factor is used. The composite random errors are of the same order of magnitude as previously reported instrument random errors of ±3% for 1½ standard deviation. These errors consist of the instruments random error combined with random errors associated with inconsistencies and anomalies of the test technique, fitting and duct setup. The average random error values varied with the instrument, velocity and fitting, but all fell within a 3% band; the high was 3.4% and the low was 0.4%. These values are within acceptable field measurement work but must not be neglected when specifying test or balancing tolerances and results. The author recommends that random error as a contributor to instrument and airflow measurement error, should be statistically determined in laboratory tests using statistical sampling methods, multiple instruments of each type and different instrument readers. Tests should be performed for all common instruments being used in the field measurements. The amount of random error of each instrument for specific velocity ranges, applications or use techniques should be determined. Specific calibration procedures should be prepared and adopted for each type of instrument to provide a consistent baseline for application of fitting correction factors.

Macferran (#13506, 1999) compares the effectiveness of the equal area approach to measure airflow in a rectangular HVAC duct section, with the seldom used procedure called Log-Tchebycheff. The author conducted tests and found that the equal area method always showed an error of from 5% to a consistent 9% up to 20% above the actual airflow – which supports statements made in ASHRAE standard 111-88. However despite this and many TAB contractors acknowledgement that there is little or no difference in contract cost labour and time between the two methods, The equal area method used almost exclusively in the US with the differences in results dismissed as insignificant. Developed in 1977, by a mathematician Tchebycheff , who developed his own methods of measuring air flow in round rectangular and round ducts. The methods were published in ISO 39663. about 10 years later these methods were adopted by the US institutions AABC and NEBB, as an option to the equal area method for rectangular ducts and the log linear method for round ducts. The authors states that no contracted AABC or NEBB company has used or will use the log–Tchebycheff method for rectangular ducts . (The log Tchebyceff and long linear method for round ducts produce the same results). In traversing a duct holes are cut down one side or across the top or bottom of the duct at spacings determined by the method being used. A measurement probe, such as an hot wire anemometer or Pitot tube then is inserted in the first hole. The dimension of the duct walls and the method being used determine the depths to which the probe is inserted and the number of air velocity measurements. The larger the size of the duct the greater the number of traversal points, regardless method) The process is repeated for each hole, with the readings taken at all traversal points then added, averaged and multiplied by the ducts cross sectional area to determine volumetric air flow. Interestingly the algorithm that determines the spacing of traversal points for the equal area method results in equal distances between points, while the algorithm for the Log Tchebycheff method results in a higher density of readings two wards the middle of the duct, as well as readings closer to the walls, which better approximates the shape of the air stream. The author has compared the two methods and found that the equal area method overstates air flow, which can be attributed to the measurement and averaging of only the air velocities of the interior. The log Tchebycheff method on the other hand, takes into account lower air velocities caused by friction and other phenomena – along duct walls and in duct corners, which are averaged with higher air velocities of the interior. In all the equal area method will give proportionally more inaccurate results, relative to the log-Tchebyceff method. The consequences of this is that systems certified field tested and balanced well operate with less air flow than recorded. In hospitals quantities of operational supply air and outside air for operating rooms and other areas always will be less than specified and be in violation of codes, affecting space to space pressure relationships. The operational energy efficiency ratio of cooling equipment and the coefficient of performance of heating and cooling equipment will be less than specified and consequently be in violation of the energy codes. Manual dampers in ducted systems will need excessive throttling which wastes energy. Fan efficiency will be less than specified and be in violation of the energy code. And outdoor air ventilation make up air will be less than specified and e in violation of applicable code. In conclusion the author states that since he has been specifying in construction Tchebycheff method be used for rectangular ducts there have been no disputes or claims for additional costs during bidding or after a contract was awarded. And he has had no post construction air flow distribution problems, air pressure problem and air noise problems on any of 80 projects.

Besant and Asiedu (#13513, 2000) discusses a new least life cycle cost, three stage procedure for air duct system design. The initial duct sizing, pressure augmentation and size augmentation method (IPS) has the potential to reduce ducting system life cycle costs and the time it takes to design them. Ducting systems are complex and expensive, being one of the major electrical energy consumers in industrial and commercial buildings. The life cycle operating costs for ducting air supply and exhaust systems often exceed first costs. Poor design and installation of an air duct system can lead to wasted energy and or excessive ductwork material. If newly installed duct system does not satisfy the specified airflow rates for each room, they require time consuming balancing. Air duct system design, usually begins with a duct system layout and specified airflow rates. The designer selects and specifies materials for ducts fittings, duct sizes and fans. The overall LCC of a duct system includes first costs and operating costs. With increasing size operating costs decreases while capital costs increases. A procedure is required to balance these conflicting cost elements to determine the duct sizes needed to minimise the LCC of the duct system and to satisfy all design constraints. ASHRAE recommend three design procedures, the equal friction method, static regain method and the T method. The equal friction and static regain methods are non optimising methods that rely on heutistics that do not account for prevailing local economic conditions. These single step design approaches result in designs that are workable but arr not cost efficient. The T method is an LCC optimising method. It consists of three main steps, ducting system condensation, fan selection and system expansion. Although the T-method is the most widely used optimisation approach in air duct design, this method dors not address the constraint dealing with standard duct sizes very well. For duct system with a large number of components this method does not ensure that the design in optimal. More importantly the process of system condensation and expansion requires many computations. The new IPS method eliminates the need to condenses and expand the system. And also avoids using a heuristic by choosing a standard size based on the optimal LCC. Although the initial sizing of the duct sections can be undertaken using a set of equations a chart (enhanced friction chart) has been developed to aid with this process. One major constraint on the air duct system is the equality of pressure drop between any two paths. This is achieved by balancing the pressure drops among each of the flow paths. The procedure outlined for initial sizing does not consider this. Where a system is not adequately balanced, the sizes of the ducts must be modified to ensure an acceptable pressure balance. This process has been seen as an art that depends upon the skills of the design engineer, (the authors notes that a systematic approach to this process, other than trail and error has not been found in the literature). The author continues to present an algorithm for balancing a duct system. The process of pressure balancing requires the value of the duct occurrence densities. (0.33, 0.33, 0.67 and 1 for duct sections 1,2,4 and 5 respectively) The results of the method outlined in the paper show that the smaller duct size increases the system pressure that results in a slightly higher cost than the T- method design. This indicates that the IPS method is capable of determining the optimal design while avoiding the tedious mathematical computations associated with the T method. The author concludes that the new algorthium for pressure balancing eliminates guessing or the need for an exact analytical solution. With the IPS method the overall fan efficiency must be known or assumed but the final fan selection is made after the ducting system pressure drop is calculated for the least LCC design. The enhanced friction chart is a tool that is easy to use and yet incorporates all the important LCC cost factors in the first iteration of the design procedure.

6.0 Testing and Balancing as part of the Commissioning process

Gupton (To be added to AIRBASE) 1986, #13495, 1988) defines systems commissioning as "start-up and check-out" and it involves testing and system balancing as well as a general clean up of all the little details that have been left undone from the construction phase. The requirements for the preparation for testing and balancing takes the form of a formal checklist, which includes key elements such as verification that air distribution products have been installed and given a preliminary adjustment, verification that lubrication of equipment is complete and also verification that rotating equipment has been aligned and that belt drive tension has been adjusted. Only when such details have been examined and correct can the system be put into operation and balanced for optimum performance.

According to Lawson and Gerdon (#13494, 1994) the field of testing and balancing (T&B) ventilation systems has developed in the US since the foundation of the Associated Air Balance Council (AABC) in 1965. Despite the existence of a number of standards, issued by ASHRAE, AABC and NEBB, in order to ensure that it is carried out in a proper and controlled manor, it has become a scientific practice, although not a defined science. These standards, such as ASHRAE 111, outline the process of T&B, the forms to be used, the instrumentation, the requirements to accomplish the job and in some cases the qualifications of the staff undertaking the testing process. However these standards neglect to mention who is ultimately responsible for the T&B process, the contractor, the engineer or the owner, and it is this question that the authors state is the major problem associated with the T&B process. The mechanical engineer is the most likely person who is asked to accept the responsibility for the T&B work. However this invariably has cost implications, since it represents one item not actually seen by the owner or occupier, and as a consequence often suffers when budgets are reduced. The authors suggest that when the specifications are being developed the owner should accept responsibility for procurement and administration of the T&B portion of the contract. In this way the owner and engineer can be more assured that if the system is not working correctly they will be advised of it properly and quickly for the necessary corrective action to be taken. The authors further suggest that the owner should hire a T&B company directly, because this can give an unbiased view, they will can talk directly to the owner passing on the necessary operational information first hand, and also the owner obtains direct control of quality assurance service, gains long term savings in operating costs, an objective T&B services and even reduced energy consumption. However, this does require more effort on the owners part, and some initial higher first costs, as well as the need for a technical person on the owners staff. The authors go on to discuss the selection of the T&B specialists and what is required from them as well as from the owners of the building before work has begun and after the completion.

Underwood (#13496, 1993) examines how commissioning affects the building owner and maintenance contractor. Underwood states that the testing and balancing contractor has a major responsibility in the commissioning process since they have responsibility of making the systems perform to meet maximum flow but also to ensure that these systems will be able to perform at part load or be adjustable to a variety of conditions. All equipment used in the balancing process should be calibrated and this information should form part of the commissioning documentation. The commissioning agent should spot check the balancing information to assure the operations and maintenance management personnel that the reports are accurate, particularly at part load conditions. The building occupancy, weather conditions and time of year should also be included, as balancing is normally undertaken at a definite time. The author suggests that to completely commission a building system will normally require four seasons to determine the adequacy of these systems for ongoing building operations over the life cycle. Any operations and maintenance staff should also be present during system balancing, this ensures the O and M staff have adequate knowledge of the process and information being recorded, and enable the staff to be able to make future system changes with an understanding of the impacts such changes will have on the rest of the system. It will also serve to show the O and M staff the required instrumentation to properly balance the systems in their particular building. After this process is complete the contractor must submit report to the O and M staff outlining a permanent record of the balancing stats of all systems at building acceptance so future changes can be made from a known baseline. ASHRAE 1989 "ASHRAE guidelines for commissioning of HVAC system 1-1989, shows the required US documentation to complete this report.

Just how much should the design engineer should expect the testing, adjusting and balancing agency to do? is the question posed by Richardson (#13504, 1994). The author outlines the variety of standards and guidelines governing TAB in the US HVAC industry as well as the types of recognised US qualifications that a TAB technician should hold. But more interestingly he outlines the typical things to look for when hiring a TAB company. For instance, should include the costs of establishing functional performance procedures and documentation procedures that are acceptable to the design team (these procedures should identify individual systems and methods of testing, if variable volume, through a full range of air or water flow). In all nine main issues are covered often with a number of sub issues also discussed. Richardson notes that each of these items can be modified to fit the actual job conditions. There could be other costs, such as mobilization, existing building systems tests etc, but the main idea is the TAB agency will be part of the consultant team and once hired special testing can be considered when warranted by the team. During the design stage the testing and balancing engineer should be part of the design team, identifying practical experiences with various types of systems. During this stage the testing and balancing engineer will become familiar with the mechanical plans and specifications and note any items that will assist the project in the functional testing stage. A functional test outline for the project will then be prepared outlining how the system will be tested and documented. During the construction phase, the assigned TAB agency will be fully involved in all aspects of HAVC installation, including scheduling, duct pressure testing, functional performance testing, observations reports on the piping, ductwork return air paths and building envelope. After the contractor has performed the equipment startup, on the whole system, the contactor will notify the owner and the TAB agency that the systems are ready for functional performance testing. Procedures established at the design stage should then be followed and findings documented. During the functional performance testing the operations and maintenance personnel should be trained, to observe air side testing, observe hydronic testing and to undertake troubleshooting techniques, t o methodically verify a complaint and report if during the occupancy stage of the project. During the occupancy stage, space temperatures should be observed to ensure the system operates within design tolerances. Adjustments should be documented and submitted as revisions. If the system cannot reach or maintain comfort conditions the design engineer should be contacted and asked to re examine the design parameters for the project.

Cohen (#13503, 1995) considers the role of performance testing in the HVAC industry. During construction the HVAC systems are erected and stared up, the automatic control system is set into operation and the testing and balancing of the airflow and water flow systems is completed. Once the testing, adjusting and balancing (TAB) report has been submitted the HVAC systems construction is complete. However the author suggests that in his experience there is no effort to verify the performance of the HVAC system, its sub systems or components. Similarly there is no acceptance tests to establish that the as-built performance of the HVAC system is in accordance with the design intent. The concept of final acceptance tests, should commence upon completion of the construction of the HVAC system, and includes automatic controls and the TAB of air and water systems. Also include are verification of the accuracy of the TAB reports and the performance of the automatic controls system. These tests examine the as built functional performance of the system. The authors suggests that there is a need for the HVAC industry to develop methods and procedures to provide for positive ventilation requirements to be established, controlled and tested for acceptance and certification. The present paper addresses the steps involved in the design, construction and testing of an HVAC system to ensure the delivery of satisfactory IAQ in a building.

Tomlinson (#13505, 1990) emphasis that in today's modern economy the role of the Testing Adjusting and balancing engineer should be considered by the building owner or facilities manager be as a requirement rather than a luxury in the overall HVAC design/construction/operation of a building. Especially with the increasing desire to improve operational efficiency. The author suggests that a first step in making TAB a working tool, is to determine who is responsible for specifying, procuring and selecting TAB services. The owner should consider contracting out the problems to a TAB firm who will have a variety of advantages over appointing in house staff or letting the contractor appoint a firm. If a TAB firm has been appointed by the owner, they are less bias, and will be more willing to point out problems. The owner can discuss the TAB work, directly with the TAB firm, thereby gaining valuable insights into the system prior to its operation. The owner can discuss the final report in detail with the TAB firm and any deficiencies noted. The selection of a TAB firm, should be based on professional qualifications ,and experience rather than solely on price. Although the selection of a TAB firm varies, the preparation of a detailed TAB specification is vital if the firm is to fully address the relevant issues. Such a document should state that the owner is seeking proposals for TAB services and that the owner will contract directly with the TAB firm. Also overall project scope, project description and location, minimum qualification of the TAB firm, insurance, bond etc, required test devices and calibration certification, progress walk throughs', interface with the owner and final report. Once appointed the owner should request the firm study the project mechanical documents and present a list of possible questions that may arise. Such interaction enables the TAB firm to be properly aquatinted with the system prior to the actual balancing procedure taking place. Once TAB work begins it is important to provide the main construction contractor with an informative list of field deficiencies. The author suggest that whilst the final TAB is undertaken during only one mode (either heating or cooling), the TAB firm should be asked to return once seasonal changeover has been undertaken . This is especially important with VAV systems or is the initial TAB work was carried out in the heating season.

Dyke and Koops (#13508, 1995) discuss new approaches to verify testing and balancing HVAC systems. Over recent years Commissioning, an expanded verification process, has gained prominence, in large part due to the increase in sophistication of micro-processor based controls. A critical part of the commissioning process is testing, adjusting and balancing. Most TAB problems are rooted in areas affected by temperature controls. The author suggests that to reduce confusion TAB procedures should therefore be placed in the hands of the controls contractor. A problem with conventional TAB practices, include minimal accountability due to shared responsibilities amongst contractors, insufficient contractual provisions for TAB contractor's contribution to problem solution and potential conflict of interest by having TAB work sub contracted the mechanical contractor. In addition there is system problems associated with the specialisation necessary to understand and manipulate temperature control system components. Often specifications call for a independent certified TAB firm to bid as a subcontractor to the mechanical contractor. Another approach is the TAB firm contracted by the owner, construction manager or general contractor. Or the work can be included in an contract to a third party commissioning agent. The author uses a VAV terminal reheat unit as an example, and examines the likely problems and who is in fact responsible for the problems including the controls contractor, design engineer, manufacture and TAB contractor. Generally when the performance problem arises the burden of proof correctly lies with the TAB contractor. Unfortunately after the problem has been identified he may still have to retest, possibly several times, which may constitute extra work, which he might have to fight for payment. His contract almost never gives him authority for coordinating solutions, yet there are great expectations put upon him for these responsibilities. To compound the problem, the TAB contractor is a subcontractor to the mechanical contractor. Conflicts of interest can therefore surface no matter how roles and responsibilities are assigned. In recent years, the design and installation of temperature controls systems, have become more problematic. Microprocessor based control systems are more complex than their pneumatic predecessors. The software is often designed by another company, who does not fully appreciate the function of the specific control. This results in a less than optimal controls system, which should be the heart of a good HVAC system. In answer to these problems, the author suggests that the TAB procedures be put in the hands of the controls contractor. At the design stage it is important to identify control system needs and owner expectations for functional intent, system access, expansion capability and cost. The intent is to maximise single-source control and responsibility for control, set-up and performance. The controls contractor must provide system verification/testing adjusting and balancing services for all HVAC systems. If the controls contractor cannot undertake this work, it should be contracted out to a qualified TAB contractor. The commissioning agent will spot check system balancing after submission of the balance report as part of the review process. The controls contractor will be required to demonstrate all control systems in all modes of operation to the commissioning agent as a review for final compliance with operational intent. Functional performance testing must be approved by the design and commissioning agent prior to field testing. Any faulty or incomplete control system installation found during this process and resulting rebalancing will fall within the contractors scope of work. The author suggests that with the increasing complexity of temperature controls with a HVAC system, it is important to make certain that the controls contractor has adequate understanding and resources available to install a high quality system consistent with the engineers design intent.

Gupta (#13500, 1997) emphasised the importance of testing adjusting and balancing (TAB), in that they must be repeatable to ensure systems are both functional and reliable. Engineers must therefore consider TAB procedures when designing systems . One of the biggest challenges specifiers face stems from the difficulty of measuring airflow in main ductwork and matching fans to systems curves. The author suggests a thorough understanding of fluid flow, pressure loss and frictional losses throughout the ductwork where essential when designing properly designed and balanced ventilation systems. A further problem is the determination of a the velocity profile. The continuity equation indicates that a system's air volume can be measured if its velocity is known. However, accurate measurement is possible only id a smooth velocity profile exits within the air stream If the velocity profile is irregular more measurements are required and the accuracy will be reduced. A number of air stream components can disturb the velocity profile, including branch takeoffs, fittings and transitions that redirect airflow. Accurate flow readings cannot be made unless the measuring device is located several duct diameters downstream and upstream from elbows and other transition pieces. Air measurement on the discharge of fans also must take air velocity profile changes into account. The velocity pressure at the fan's discharge is non-uniform it takes some distance for the air to acquire a smooth profile. It is also advisable to take several readings in a duct to get more accurate reading of the airflow. The author also suggests that the concepts of total, static and velocity pressures are often misapplied when fans are selected and "system–effect" factors are often ignored. Where ductwork static- and velocity pressure changes largely result from the duct's size. The correct method to size fans is to calculate the sum of the total pressure drop through the supply duct and add this total to pressure drop through the return-air ductwork. Changes in the air velocity and static pressure as it goes through the supply and return ductwork, is irrelevant from the viewpoint of the fan and its rating. Confusion can result when total pressure drop due to frictional and dynamic losses occurs in a duct with a constant cross sectional area. In this case total pressure drop equals loss in static pressure because velocity pressure remains the same. The author also highlights a number of system effect factors, such as those associated with duct fittings for example, incoming air spinning at the inlet in the opposite direction of the wheel, or non uniform airflow in the inlet. Such system effect factors do not affect published theoretical fan curves, but system curves will shift upwards. If system effect factors are present the system curve moves up and the actual point of fan operation will also be higher. In conclusion the authors stress that system designers play a vital role in the success of TAB efforts. For example, volumetric flow rate measurement can be improved if designers incorporate space in the ductwork where a smooth velocity profile can develop. Also designers must bear in mind, that fans should be sized based on total pressure, not static pressure. And finally designers must consider system-effect factors that can distort results delivered by TAB contractors and imply that fans are not meeting their published ratings.

Parsloe (1998) notes that the principle design aim is that the selection of ductwork, components, configurations and layouts which will ensure that the system is as inherently stable and self balancing as possible. The self balancing characteristics of the ductwork distribution system may be improved by considering the following design options:
1. The sizing of ducts, where appropriate by the principle of static regain. This method will help to ensure that approximately the same static pressure exists at the entrance to each terminal branch therefore simplifying the balancing procedure.
2. The selection of duct sizes to roughly balance the pressure drops across sub branches or terminal branches.
3. The avoidance of terminals with different characteristics on the same run. For example veiling diffuses and side wall grilles, or ceiling diffuses and combined air/lighting fittings. If the mixing of such terminals is unavoidable , provision must be made for in duct measurement on the sub branches.
4. The use of stub ducts to connect terminals to a main or principal branch duct. If direct connection cannot be avoided , turning vanes should be incorporated.
5. The avoidance of splitter dampers to divide flow - these will complicate the balancing procedure.

The publication outlines the various measurement equipment used to adequately test and balance the ventilation system. The BSRIA preferred balancing procedure is the proportional method. This method is outlined at length. However they state that successful application of the technique is dependant upon the inclusion of sufficient regulating devices suitably positioned in the ductwork installation. The balancing procedure outlined assumes that such devices have been installed in the ductwork branches to every terminal.

Schultz (#13499, 1990) attempts to show how testing and balancing a ventilation systems can improve the energy use and performance of these systems. Initially as energy costs throughout the world rise, ensuring the efficient and effective use of major users of energy becomes increasingly more important. The result is that testing and balancing (or adjusting as the author calls it) industry will thrive. The importance of the indoor air quality is another important issue. The authors suggest that “sick building syndrome” is a result of overly aggressive energy conservation practices implemented by owners and maintenance staff. Examples cited include the closure of air dampers and general sealing of the building envelope. The resulting reduction in energy costs is accompanied by an increase in absenteeism, reduction in productivity and increase medical treatments, not to mention the possible damage to the building structure and internal space. The adoption of ASHRAE 62 has lead to increased ventilation rates per occupant. However, even small adjustments of the outside air dampers minimum position at winter and summer design limits is of critical importance to both indoor air quality and energy costs. Radon is another issue, common techniques such as sub slab depressurisation and sealing cracks and openings has proved ineffective. A more effective approach according to the author is it properly adjust a buildings air distribution and exhaust system to maintain a continuous positive pressure. Instruments can confirm system – operating air volumes and building static pressures under all conditions of varying outside air, return air and exhaust air dampers. Buildings with elevated radon levels may run mechanical systems 25 hours a day every day. Weekend or night shutdown would neutralise building pressure and allow radon levels to rise. Qualified testing and adjusting, along with radon monitoring plays a critical role in keeping a building environmentally safe. Building pressurisation also has other benefits, such as increased gas or oil fired equipment efficiency and increasing building structural component life.(Warm air forced out through the walls reduces condensation risk). However most building are kept in negative pressure, as it costs money to pressurise. The author nots that it is important to maintain a slightly positive pressure under all occupancy conditions. Only qualified testing and adjusting staff can properly adjust the air intake and exhaust ratio and accurately measure the degree of pressurisation.

The importance of proper and correct TAB in HVAC ductwork is stressed in Carrie et al (#12875, 1999) who state that ductwork should be tested and recorded and details should be included in the manuals for operation and maintenance. Detailed drawings of the ductwork installations, specifications for materials and devices as well as for maintenance schedules shall be available to building managers to ease maintenance and retrofit. This report focused on the overall tightness of ventilation ductwork, and says little about how the overall ductwork can be balanced to give the correct flow and vents.

Cohen (#13503, 1995) considers the role of performance testing in the HVAC industry. During construction the HVAC systems are erected and stared up, the automatic control system is set into operation and the testing and balancing of the airflow and water flow systems is completed. Once the testing, adjusting and balancing (TAB) report has been submitted the HVAC systems construction is complete. However the author suggests that in his experience there is no effort to verify the performance of the HVAC system, its sub systems or components. Similarly there is no acceptance tests to establish that the as-built performance of the HVAC system is in accordance with the design intent. The concept of final acceptance tests, should commence upon completion of the construction of the HVAC system, and includes automatic controls and the TAB of air and water systems. Also include are verification of the accuracy of the TAB reports and the performance of the automatic controls system. These tests examine the as built functional performance of the system. The authors suggests that there is a need for the HVAC industry to develop methods and procedures to provide for positive ventilation requirements to be established, controlled and tested for acceptance and certification. The present paper addresses the steps involved in the design, construction and testing of an HVAC system to ensure the delivery of satisfactory IAQ in a building.

When establishing the IAQ procedures in an HVAC system, there are two major concerns. 1. Set up and verification the minimum OAI rates and the minimum exhaust air flow rates at the HVAC unit. 2. ensure that the minimum OAI airflow rate is delivered to each occupied space. Measuring the airflow at the HVAC unit presents a difficult task. The TAB contractor must utilize each available measurement technique to verify the flow rates. May include pressure differentials across fixed damper and /or louver openings, coil traverse techniques etc. It is possible that equipment manufacturers will develop procedures to simplify these measurements because they are vital factors in establishing the required IAQ. To ensure the distribution of the minimum OAI rates to each occupied space, the design engineer is required to analyse the minimum airflow requirements for the entire HVAC system. This data is then used to determine the maximum airflow requirements at each terminal. In fan powered terminals with reheat coils the minimum proportions or primary air can be relatively high without overcooling the space. For VAV terminals without reheat service, the proportion of cool primary air is adjusted to prevent overcooling of the space. The design engineer will make these determinations and the TAB contractor will implement the requirements in the final TAB adjustments. The author concludes by empathizing that the TAB contractor and the acceptance tests contractor are completely separate. The TAB of the HVAC system should be completed and the final reports submitted, reviewed and verified before beginning the acceptance tests. Provide the final acceptance tests indicate an agreement with the design intent, the system is passed. If there are discrepancies, then additional TAB may be required. The author notes that the design documents should specify the TAB contractors responsibility for the rebalance of systems or portions of the system without additional payment, to satisfy the requirements of the final acceptance tests.

7.0 Standards, Codes of Practice and Guidelines

According to the American Air Balance Council (AABC) who issue their own guidance of ventilation system balancing procedures they define Total System Balance as…. *"the process of testing, adjusting and balancing environmental and other systems to produce the design objectives. Each air treatment process in the conditioning system contributes a specific function to produce proper environmental conditions. However, it is coordinated action of all these processes in a system that produces the desired conditions. Total system balancing is the process of testing, adjusting and balancing each system component so that the entire system produces the results for which it was designed. It is a science that requires proper use of instruments, evaluation of readings and adjusting the system to design conditions."*

ASHRAE 111-1988 "Practices for measurement, testing adjusting and balancing of building heating ventilation air conditioning and refrigeration systems", outlines the instruments required to carry out testing and balancing of HVAC systems. Their recommended uses, limitations, expected levels of accuracy and calibration requirements are also included. As well as the how to obtain the required measurements. To ensure that the system can be adequately adjusted, balancing stations are installed along the ductwork. These are composed of a measuring device (to obtain velocity pressure, Pitot tube and manometer), a balancing device (to control flow rate (an opposed blade damper or venturi plug type damper) and straight sections of duct (minimum 5 preferred 10 duct diameters downstream of measuring device). Importantly no sensing probes regardless of size should be in the upstream straight section. Such balancing stations in the main ducts are used to measure the fan total airflow, whilst in other ducts to measure and adjust the distribution of the air. The required accuracy of these stations should be ±5%. An air balancing devices are commonly called volume control dampers, control the airflow to achieve a balanced distribution of available total airflow. The type of damper depends upon the pressure drop across a throttled damper. The standard highlights 5 pressures (75Pa, 75-500Pa, 500-1000Pa, 1000-1500Pa, and 1500 Pa and corresponding acceptable devices. It also outlines damper types that are not recommended. Conditions that can have an adverse effect on system performance, known as "System effects" are also discussed. These cannot always be measured in the field, but can be estimated with the use of tables and charts etc. For example fan inlet and discharge conditions, ductwork system losses, ductwork construction, including leakage and duct system devices and balancing. The standard also outlines how to prepare the system and obtain the required data and how to carry out a system balance and adjustments when necessary. Prior to testing, updated construction diagrams, specifications or any changes or updates to the original system specifications should be obtained and consulted. All field data sheets should be prepared, system leakage rate date where duct leakage testing is specified. Verification that fans are installed, function correctly and all maintenance and safety requirements have been met. Check filters are clean, fire, smoke, automatic and volume control dampers and operable, accessible and are in an open normal position. Controls are operable and calibrated, boxes and terminal devices are installed and accessible, and that all access doors are installed and secured. There then has to be some technical checks to ensure the system is ready for balancing, these include verification that all dampers are open and all boxes or automatic air volume control devices are in an acceptable mode, that all terminal deflectors are in a position indicated by the manufacturers data. The standard then outlines the two main methods of system balancing, the traverse and the proportional methods. The standard touches on special systems, including constant volume, variable volume, and induction systems.

The Swedish National Board of Housing, Building and Planning's requirements relating to compulsory performance checks of ventilation systems and guidelines for inspectors are outlined by Anon (#10855, 1992). The guidelines note that defects in ventilation systems are often simple to remedy. Sometimes it is only a matter of changing a filter or fan belt or cleaning a dirty ventilation unit. Ensuring that mistakes and defects are discovered and dealt with in time, requires proper and adequate maintenance and inspections. In the long run, providing better return on capital investments and lower overall operation and maintenance costs. The report cites the introduction of the Swedish regulation (1991:1273) about checks on the performance of a ventilation system, the owner of a building shall be responsible for ensuring all checks are carried out, both before a ventilation system is brought into use for the first time as well as at regular intervals during the building's lifetime. If the owner of a building does not follow this regulation or fails to remedy stated defects, the municipality can order the owner to carry out the required measures and if necessary link this to a fine. Examples of what is meant by "regular checks" include Day care centres, schools, health care centres etc (2 years), Blocks of flats and office buildings with balanced ventilation (3 years), Flats and offices with mechanical exhaust ventilation (6 years), Flats and offices with natural ventilation (9 years) and one and two dwelling houses with balanced ventilation (9 years). The document highlights the required qualifications of inspectors and how such inspections should be carried out. The report also suggests a wide variety of specific aspects which should be checked, as well, including, deposits in ventilation ductwork and the quality of any recirculated air. The document is a pointer to the various Swedish regulations and documents covering these issues rather than discussing the actual problems and their solutions.

Persily (#7485, 1994) presents a manual, which describes procedures for assessing ventilation system performance and other aspects of building ventilation in mechanically ventilated commercial buildings. The manual is aimed at technically competent indoor air quality investigators, building operators and others who need to perform ventilation assessments in order to address existing problems or as part of preventative maintenance programs. Background information includes discussions about what is the nature of air, pressure, density, speed and measurement. An outline of a ventilation system and its components, and in the instrumentation needed to undertake an effective evaluation of the airflow within the system. Not only is instrumentation covered, but also how to undertake measurements of air temperature, humidity, differential pressure, static pressure, and the use of flow hoods, smoke tubes and Pitot static tubes are all explained. Persily notes that when evaluating the performance of a ventilation system, the building layout, system design and the purpose of the evaluation must be considered in order to determine which system parameters are measured and the procedures used in these measurements. There are no set list of parameters and evaluation procedures that can be used in all buildings under all circumstances. Three types of ventilation evaluation procedures are described: space use analysis, system design evaluation and performance measurement. Space use analysis provides information on ventilation requirements of a building. System design evaluation is used to determine how the ventilation system is intended to perform, and performance measurements provide information on how the system is actually operating. The first step of a Space use analysis is to list the major spaces or zones in the building. Then determine the ventilation requirements of the building zones based on the space type and the number of occupants. Finally thermal loads are then assessed.

The system design evaluation describes how the ventilation system is intended to perform based on the design documentation. The results of this analysis can be compared with ventilation requirements from the space use evaluation to determine if the system is adequate for the current use of the building. A list of parameters are given, and includes both numerical values, such as airflow rates and descriptive information, such as operating sequences. The list includes Design conditions, data on the supply fans, return fans, outdoor air fans, air distribution system and the exhaust systems. An important source of information is the testing adjusting and balancing report. Air balancing is performed late in the building construction process but may also be performed at other times in the life of a building. Air balance reports should contain design supply air flow rates for fans, terminal units and diffusers. The minimum outdoor air intake rate may also be included. The report also contains data on measured airflow rates. Finally performance measurements enable evaluation of pressure relationships in the building and to measure air change rates. In constant and variable air volume systems measurements should be made during minimum and maximum outdoor air intake. For VAV systems these should also be measured and compared against situations of minimum and maximum thermal load. The performance of air handlers, air distribution systems, terminal units, and supply air outlets should be evaluated. As well as an evaluation of the effectiveness of the system by an examination of the ventilated space, the effectiveness of the exhaust system, and examination of the relative building pressure relationships (those across the exterior envelope, and between adjoining spaces), and whole building air changes rates.
These assessment methods can help with preventative maintenance, air quality diagnosis and energy assessments, leading in a better performing system and building, in terms of occupant health, comfort and owner costs.

In a design and installation manual for residential mechanical ventilation systems published by the Alaska Craftsman Home Program (#12420) construction details to reduce energy consumption and moisture damage to dwellings in Alaska are outlined. In this region without mechanical ventilation normal activities such as laundry, cooking and showers can cause excessive humidity levels causing occupant discomfort and condensation problems. As an integral part of the HVAC system installation, under system commissioning, Air flow measurement and balancing is discussed. The handbook recommends that to ensure that the design airflow requirements have been met the installer must measure the ventilation air supply and exhaust flows to and from the house at each of the design conditions. The handbook briefly outlines the measuring equipment and suggests that several HRV manufacturer market airflow grid devices designed to mount directly in the ductwork. These devices are connected directly to an inclined manometer or a magnehelic gauge, which senses air pressures in the duct. A chart provide with the airflow grid converts the measured air pressure to a flow rate. To undertake a room to room balance only the airflows at the supply and exhaust grilles need to be measured. Balancing is done by closing off dampers in high flow ducts, thus encouraging increased air flow in the other ducts. Before the ventilation air supply and exhaust flow rates can be measured and balanced the air/vapour barrier in the house must be completed. Fireplace dampers must be shut and doors and windows tightly closed. The building envelope must be in its normal closed up position. The ventilation system must be complete and all filters and register dampers set to their operating positions. When measuring airflows, ventilators are turned off and the main balancing dampers are moved to fully open position. The airflow grid or other measuring probe is then inserted into the warm side of the ducts. It is best to begin with the side that has the longest equivalent duct length (i.e. highest pressure drop, thus the lowest airflow rate). This will often be the exhaust air side of an heat recovery ventilator. With the measuring device inserted the system in started. Measured pressure readings are converted to air flows, and actual air flows should be recorded. These should then be compared to the design flow rates. If the measured flow of air in either the supply or exhaust duct does not meet the design specifications. Remedial actions should be taken. Confirmation that all fans are operating , and at the correct speeds. Then all dampers should be checked to ensure they are in the correct positions and that all inlets, filters or heat exchanges are not blocked or damaged. Check ductwork leakage. If the ventilation air supply and exhaust flow rates meet or exceed the design requirements, but violate design requirements (ie air flow imbalances exceed the allowable maximums or HRV systems are more than 10% out of balance) the system should be balanced. To balance the excessive airflows are reduced by adjusting the balance damper in the duct with the excessive flow until the air flow falls within the design limitations. If both flows in a balanced system exceed the design air flow rate, flows may be reduced by partially closing the dampers in both the supply and exhaust air streams. Once flows are balanced the dampers should be locked in position. Record the final gauge settings, remove instruments and reconnect the ductwork. While HRV flows are required to be balanced within 10% of each other, you will find that by using the above procedure it should be possible to achieve a near balanced condition. The installer should then certify the installation.

Bower (#9014, 1995) goes into a little more detail in his book "Understanding Ventilation" which focuses on household ventilation systems. In supply and extract systems the exhaust ducts have less resistance than the supply ducts, resulting in potential pressurisation or depressurisation problems. The result can be wasted energy, potential condensation (or freezing) problems, or cool drafts in the winter. For a house to be under neutral pressure the airflows must be in balance. It is unlikely that the system will be in prefect balance, at all times because of all the neutral and accidental pressures that can affect house pressures. Balancing incoming air to ±10% of the volume of the outgoing air is generally close enough. Before balancing the system local exhaust ventilation fans should be turned off and the forced air furnace /air conditioning system is off (unless their ducts are being used to distribute ventilation air). Check the ducts for blockages, and turn the ventilator on at high speed. Balancing will be affected by wind and stack effect to a certain extent, so a system balanced on a calm warm day might be out of balance on a cold windy day. This is why the ± 10% is close enough. The author briefly outlines the use of airflow grids and magnahelic gauge (to measure air pressure). To balance the system, the pressures in the supply and exhaust ducts are measured at the airflow grids and the numbers are converted to flow rates, then the higher airflow is restricted with an adjustable damper until it matches the lower flow. This is done by partially closing the damper in the duct having the higher flow or by adjusting a grille at the end of the duct. When the airflows are within 10% of each other the system is considered balanced. The authors states a that in Canada houses built to the R2000 energy efficiency standard, building inspectors check the airflow grids to see if the system is balanced. Proper distribution also involves adjusting grilles and dampers so the correct air reaches specific rooms. The airflow at each grille should be measured prior to any adjustment of grilles. The author outlines the various ways such airflows can be measured, including the use of a home made measurement hood and the use of a piece of string to compare the airflow through grilles. This wont give you the litres per second flow rate, but can tell you if the flows are roughly comparable at two or more different grilles.

The Sheet Metal and Air Conditioning Contractors National Association (SMACNA) have also published a handbook on testing, adjusting and balancing HVAC systems. This handbook presents the basic fundamentals, methods, and procedures including the necessary charts and tables designed for use by a typical SMACNA contractor. The handbook examines how to balance typical HVAC systems, including basic all air systems, supply air systems, exhaust and return air systems. As well as also outlining balancing procedures for dual duct (and single duct) constant volume systems, variable air volume systems and induction systems.

In a manual on HVAC testing, adjusting and Balancing Gladstone and Bevirt (1996), outline in great detail the main fundamentals of TAB HVAC systems. Sponsored by the US National Environmental Balancing Bureau, this book provides an authoritative outlined of TAB procedures and standards. The book examines fundamental equations, related to airflow measurement, fan selection, duct pressure losses and air and heat transfer. The manual starts by outlining standard TAB procedures, for HVAC air systems, 16 key points are identified. These are:

1. All related HVAC and exhaust air systems should be operating.
2. Determine whether any other HVAC or exhaust air systems could affect the system ready to be balanced.
3. Make Pitot tube traverses on all main supply and major branch ducts where possible to determine air distribution.
4. Adjust balancing dampers of each major branch duct that is high on airflow. A minimum of one branch duct balancing damper shall remain fully open.
5. Measure and record the airflow of each terminal device in the system without adjusting any terminal outlet. Flow measuring hoods are the preferred airflow-measuring device.
6. The total airflow for the terminal outlets should be close to the Pitot tube traverse air measurement of that branch, and the main air measurement should be within 10% of the total of all terminal outlet air measurements.
7. Check for excessive duct leakage of total terminal outlet air measurements are less than 90% of the main duct traverse air measurement.
8. Adjust the terminals that are highest on airflow to about 10% under design airflow.
9. Adjust each terminal outlet throughout the zone or system to design airflow and record measurements and make any necessary branch damper adjustments.
10. An additional adjusting pass throughout the system may be necessary. Make final adjustments to the fan drives where required. Record all data.
11. Adjust terminal devices vanes to minimise drafts and for proper air distribution.
12. Measure and record system static pressure.
13. Measure and record all outdoor air, return air, mixed air and supply air dry bulb and wet bulb temperature. Measure and record all plenum static pressures.
14. Measure and record all coil entering air and leaving air dry bulb and wet bulb temperatures. Measure and record all coil pressure differentials.
15. Measure and record final fan motor load amperages and voltages.
16. Proportional balancing procedures may be found in the NEBB Procedural Standards for Testing, Adjusting and Balancing of Environmental Systems. Many TAB technicians may find these procedures more accurate and easier to use. Others may find them more complicated.

A similar manual has been complied by Wendes (1981) who points out that air and water systems are rarely automatically balanced by themselves when they are turned on. Air balancing is needed to ensure that the right quantities of air are being delivered to individual outlets to satisfy space loads as per design, and to ensure that the fan is pumping out the correct total quantity of air. Equipment must be checked out to ensure that it meets design in terms of type, size and performance. It must be checked out to guarantee correct installation and must be adjusted to operate properly. Equipment and systems must be checked so that they run efficiently and aim to reduce energy consumption. Testing and balancing is required to detect and rectify hot and cold spaces, noises odours and draughts for optimum health and comfort. The end benefits of correct and proper testing and balancing are reduced energy consumption, lower operating costs, safer systems, reducing or eliminating maintenance call backs, prevention of premature parts were and subsequent break downs, healthier and more comfortable air for occupants, profitability, and improved reputation for your company and industry. The author outlines general methods of measuring air velocity and volume at outlets, in ducts, in plenums and at coils. These are outlined below:

1.Air velocity and volume at outlets can be measured with a velometer and diffuser probe, which is the most common method for diffusers, with a rotating vane anemometer for grilles, a flow hood at diffusers and grilles or a thermal anemometer.

2. Air volume in a duct may be read with a Pitot tube and manometer.

3. Air volume may be roughly measured by reading the pressure drop across a coil and correlating it to a manufacturer's chart or graph relating to l/s (cfm) and pressure drop for that particular coil as established at the factory.

4. The air volume can also be established roughly by determining the temperature rise of drop across a coil and in a similar manner as with the pressure drop correlate it to the manufacturers factory established chart of graph showing the l/s and temperature relationship for a particular coil.

5. Another technique for measuring air flow in a duct is used for leak testing in ductwork and by laboratories for testing purposes. The pressure drop across an orifice plate is measured with a manometer and is related to a prior established graph for the particular orifice plate, which plots l/s (CFM) against pressure drop.

The manual outlines in some detail the procedures for preparing TAB reports.

Separate chapters in the report are used to outline how constant volume supply systems, return air and toilet exhaust systems, constant volume high pressure systems, variable air volume systems, industrial and commercial exhaust as well as residential systems are balanced.

Bevirt (#13502, 1994) In the early days, of HVAC system development and design most testing and balancing work was haphazard and poorly executed, creating the need for trained qualified personal to undertake such tasks. Today standards and guidelines exists to ensure that TAB is undertaken in a correct uniform manor, to recognised industry agreed standards. However despite these guidelines and standards, some HVAC system design engineers do not provide detailed information on fan capacity selection on and do not show balancing devices on project drawings. The author suggests that there are three major problems that can develop in HVAC duct systems, some are inadvertently designed into the system, whilst others may be created by the system installers. All create problems for the TAB firm. In air systems the main problems are duct air leakage, system effect and excessive fitting pressure drops. Apart from fan selection, another problem with duct leakage is that many HVAC system designers specify a maximum of 1% leakage from systems in the 1000 to 1500 Pa pressure classification for duct construction. When fully sealed round ductwork of leakage class 3 is used, an average HVAC system with an airflow/duct surface ratio of 15l/s m^2 of duct surface will leak 1.6% at 500Pa average pressure or 2% at a 750Pa average pressure. With totally sealed rectangular ductwork the percentages increase to 3.1% and 4.1% respectively. What is obvious is teat the larger the duct system and /or the higher the internal duct pressure the greater the air leakage will be. Under such conditions it is not practical that a TAB technician can verify a 1% maximum duct leakage. The problem with system effect is that it cannot be measured in the field by TAB technicians. It may be designed inadvertently into an air system or may result of job site conditions. However system effect can be calculated using tables and charts in a number a recognised manuals. Examples include Fans and systems (AMCA 1990) or HVAC systems – Duct Design (SMACNA 1990) after a visual inspection is made of the fan/duct system connections. Job site conditions cause many changes in the way HVAC duct systems are installed. Beams that were not taken into account by the designer, piping and conduits already installed that must be avoided, on the site changes by the owner – all can add duct fittings that increase the system total pressure loss above that original calculated. Even without these additions, when turning vanes have been left out of 90° mitred elbows or every other vane has been left out of the vane fails, the installed system pressure loss will be higher. Also depending upon system layout partial closing of balancing dampers in routine TAB work may add even more system pressure to hat the fan must overcome. The author goes on to outline the TAB procedures and the variety of test instruments used in TAB as well as typical reports and acceptance tests.

8.0 Conclusions

Poorly balanced ventilations systems can cause high energy consumption in the rooms with high outdoor rates and deteriorated air quality in the rooms with low outdoor airflow rates. By balancing the airflows, the average air quality in a building can be improved and energy efficiency improved. Too low outdoor ventilation rates are also possible in VAV systems with no minimum supply airflow value. Poorly balanced ventilation will cause excessive airflows in some offices which are not economical and will most likely cause draughts. While people in offices with too low airflows all require more ventilation. Therefore more emphasis should be placed on the proper maintenance and operation of ventilation systems in general, and the balancing of airflows in particular.

After system cleaning re-balancing may be required, of particular importance are correct fan adjustment (direction and speed), correct volume airflow must be provided by fans, all volume control dampers must be set correctly, all fire dampers must be set in the open position and be fully operational. Systems should be clean and free from obstructions. All filters should be correctly installed and in the correct range of operating cleanliness. Ductwork and air handling units (fan, coils and other components) should also be clean and the system should be free from any blockage in the ductwork.

There are two main balancing methods, the proportional and traverse methods. The former aims to determine and compare the ratio of the measured flow to design flow for each outlet, branch ducts and sub-main ducts. Based on the ratio of airflow rates delivered through each branch of duct in relation to each other remains constant when the total of air supply to them varies. The traverse method, requires a Pitot tube velocity traverse of each sub-main ducts to determine flow rate through each and adjustments to the main volume control dampers, to provide the required flow through each sub-main air duct. Beginning with the sub main duct closest to the fan, a Pitot tube velocity traverses of each branch on that sub-main duct run should be undertaken.

Alternative methods have also been described such as using the constant-injection tracer gas technique to measure airflow rates in HVAC systems directly, this method does not require determination of the cross sectional areas of ducts or velocity profiles. According to the authors provide accurate measurement of airflow over a wide range of air velocities and can be used to measure airflow in ducts of different sizes, shapes and lengths and does not require a long measuring duct for the establishment of fully developed flow.

Thermography has also been suggested as a tool to balance the air flow rates in a ventilation system. From finite difference analysis of the air transfer grille, it can be seen than the surface temperature is a function of the velocity of the air passing over it, and therefore it should be possible to determine the air velocity from a knowledge of the surface temperature history. The authors however did not demonstrate that this method is very effective, the test carried out have indicated that the temperature/time history of a ventilation grille may be used to establish if the ventilation system has gone out of balance.

The expansion of computerised technologies has also led to several new techniques and methods for example, the use of Direct Digital Controllers (DDC) as an integrated device that can be used to aid the balancing of ventilation systems. Another such control system checks the ductwork and makes an automatic balancing procedure to determine the pressure drops of different ductwork components and branches. The approach outlined here is a departure from the traditional VAV system control strategy, in that it is based on knowing the ductwork geometry and calibrating the ductwork so that the intelligent control system knows the characteristics and can control the system according to needs. Thus all measurements in the normal operation are unnecessary.

Dual Pressure measurements" (DPM) is another computerised method, requiring the pressure loss calculations have been made with a reliable computer program. Which determine the optimum pressure loss line for the whole system and over individual components. By adjusting air terminals and dampers to match the pressure loss line, a system can be brought into balance even when the airflow is far off from the required value.

Commissioning is an important and vital element to any design, described as "start up and check out" it involves ensuring that the system works as it is designed to. However, there appears to be some disagreement as to who is responsible, the building owner, design engineer or maintenance contractor. However, if the client takes responsibility and employs and testing and balancing company independently, then he is more likely to get to know the full story, since there are no conflicts of interest.

It has been noted that main design aim is that the selection of ductwork, components, configurations and layouts which will ensure that the system is as inherently stable and self balancing as possible. The self balancing characteristics of the ductwork distribution system may be improved by considering a number of options, including The sizing of ducts by the principle of static regain. This will help to ensure that approximately the same static pressure exists at the entrance to each terminal branch therefore simplifying the balancing procedure. Selecting duct sizes that roughly balance the pressure drops across sub branches or terminal branches. Avoid terminals with different characteristics on the same run. Use stub ducts to connect terminals to a main or principal branch duct. If direct connection cannot be avoided , turning vanes should be incorporated. And finally avoid splitter dampers to divide flow - these will complicate the balancing procedure.

The importance of proper and adequate performance testing through the construction phase and post construction cannot be stressed enough by the many papers reviewed in this document. Finally if in any doubt, there are many manuals covering the design principals, equipment and techniques used, as well as many fundamental equations and rules of thumb that are in common use. These have been complied by organizations and individuals who care about the quality of the ductwork and occupied spaces and therefore contain much valuable information.

9.0 References.

#NO 2046 The Averaging Pressure Tubes Flowmeter for the Measurement of the Rate of Airflow in Ventilating Ducts and for the Balancing of Airflow Circuits in Ventilating Systems;
LOCATION = Europe;
AUTHOR Ma, W. Y.;
BIBINF RESEARCH.LOC = Univ. of Glasgow; TYPE = JOURNAL; #DATE 01:02:1967; VOLUME.TITLE = JIHVE; PAGES = 327-349; in English
ABSTRACT This paper describes an original investigation of a new flowmeter and a method of balancing of airflow circuits in low pressure ventilating systems. The flowmeter is simple and robust in its construction, imposes virtually no resistance to the airflow circuit, requires only short lengths of duct before and after the measuring point and is consistent in its performance. The accuracy of the flowmeter from laboratory tests was found to be better than +/- 6.5% for air velocities from 600-1400 feet per minute. The method of balancing using precalibrated air volume dampers has been shown to be reliable and quick. Only two adjustments were required to bring the airflow circuits tested in the laboratory to balance. This method took only one quarter of the time required by a 'Systematic Trial and Error' method in balancing an airflow circuit with four branches in the laboratory. Field tests on the flowmeter and the method of balancing confirmed the above findings.;
KEYWORDS = AIR FLOW; DUCT; VENTILATION; INSTRUMENTATION;

#NO 3386 Flair homes project report No.3: Design, installation and commissioning of the ventilation system.
AUTHOR Proskiw G, Phillips E G, Figley D A, Fisher D R
BIBINF Canada, Energy Mines and Resources, June 1988, 53pp. #DATE 00:06:1988 in English
ABSTRACT Tracer gas tests and balancing studies were performed on the ventilation systems in ten houses to determine their performance under actual operating conditions. The houses were unoccupied, unfurnished bungalows with identical floor plans and main floor areas of approximately 85 m2. The ventilation systems studied consisted of: 1. Combined heat recovery ventilator (HRV) forced air heating systems; 2. Dedicated HRV ventilation systems; 3. Exhaust only heat pump HRV ventilation systems (using a prototype HRV); 4. Integrated heat pump HRV, space and DHW heating systems. Recommendations were made on: measures to control duct leakage and provide better zone distribution in several of the systems, the need to verify ventilation compliance in integrated systems, testing of some HRV's at the manufacturing stage to assist in reducing leakage and the need to develop revised design procedures.
KEYWORDS ventilation system, design, installation techniques, tracer gas

#NO 4870 CIBSE National Conference 1991.
AUTHOR CIBSE
BIBINF UK, Chartered Institution of Building Services Engineers 1991, proceedings of conference held University of Kent, Canterbury, 7-9 April 1991, 549pp. #DATE 00:00:1991 in English
ABSTRACT Proceedings of a conference held at the University of Kent, Canterbury, 7-9 April 1991.
KEYWORDS building design

#NO 5690 Balancing airflow in HVAC systems using tracer gas techniques.
AUTHOR Riffat S B
BIBINF UK, University of Nottingham, Dept of Architecture and Planning, April 1992, 14pp, 9 figs, 5 tabs, 1 ref. #DATE 00:04:1992 in English
ABSTRACT The present study describes new equipment which could be used to balance HVAC systems. The equipment allows the constant-injection tracer gas technique to be employed and has the following advantages over existing balancing methods: i) It is simple to use and allows HVAC systems to be balanced in ashort period; ii) It can be used to measure airflow rates in HVAC systems directly and does not require determination of the cross-sectional areas of ducts or velocity profiles; iii) It can be used to provide accurate measurement of airflow over a wide range of air velocities; iv) It can be used to measure airflow in ducts of different sizes, shapes and lengths and does not require a long measuring duct for the establishment of fully-developed flow.
KEYWORDS air conditioning, tracer gas measurements, instrumentation

#NO 7062 Balancing ventilation systems using thermography.
AUTHOR Ward I C
BIBINF UK, Air Infiltration and Ventilation Centre, 14th AIVC Conference, "Energy Impact of Ventilation and Air Infiltration", held Copenhagen, Denmark, 21-23 September 1993, proceedings, pp525-532. #DATE 21:09:1993 in English
ABSTRACT It has been shown that thermal imaging can give an indication of air flow rates through small cracks. Using a finite difference analysis package it is possible to determine the surface temperature of an air transfer grille when subjected to airflow rates at higher temperatures than the grille surface. This paper will address this technique by presenting the results of the finite difference analysis package for a specific grille. It will then present the results of a series of experiments to calibrate a range of air

transfer grilles using thermal imaging,and finally will demonstrate how the technique can be applied tochecking the air flow rates in a ventilation system.
KEYWORDS ventilation system, thermography, crack, air flow

#NO 7468 A measurement technique guide on the application of tracer gas techniques for measuring airflow in HVAC systems.
AUTHOR Cheong K W, Riffat S B.
BIBINF UK, University of Nottingham, School of Architecture, Building Technology group, (pre print) 1994, 137pp, 73 figs, 21 tabs, 42 refs.#DATE 00:00:1994 in English
ABSTRACT This handbook describes the use of tracer-gas techniques for measurement of airflow in ducts. Initial measurements were carried out in the laboratory to examine the accuracy of these techniques. The mixing of tracer gases (eg, sulphur hexafluoride, SF6) in ducts of various shapes and sizes was examined using different types of tracer injector.Airflow estimated using tracer-gas techniques (eg. constant-injection, pulse-injection) was compared with measurements made with traditional instrumentation such as Pitot-tubes and hot-wireanemometers. Work also involved the development of tracer-gas equipment for balancing airflow in HVAC systems. This equipment was used to balance airflow in a small-scale HVAC system.Research also involved the development of a perfluorocarbon (PFT) tracer-gas sampling system. The PFT was injected using a thermostatically-controlled injection unit and a fast-response sampling system, using stainless steel tubes packed with adsorbent, was employed to collect tracer gassamples. The samples were analysed in the laboratory using a thermal desorber and gas monitor. The PFT system was tested successfully in the laboratory. Airflow measurements were carried out in the HVAC system of an office building using tracer-gas techniques and the new lPFT technique.Tracer-gas techniques were used in other applications including measurement of airflow through a porous medium in a rectangular duct and determination of the air-tightness of ductwork.
KEYWORDS Measurement technique, tracer gas, air flow, air conditioning.

#NO 7485 Manual for ventilation assessment in mechanically ventilated commercial buildings.
AUTHOR Persily A
BIBINF USA, National Institute of Standards and Technology, Building and Fire Research Laboratory, NISTIR 5329, 123pp.#DATE 00:00:1994 in English
ABSTRACT This manual describes procedures for assessing ventilation system performance and other aspects of building ventilation in mechanically ventilated commercial buildings. These procedures are intended to provide basic information on building ventilation for comparing ventilation performance to standards, guidelines and building design values and for investigating indoor air quality problems. The procedures in the manual are based on established measurement techniques and available instrumentation and provide practical means for obtaining reliable information on ventilation performance. The manual does not describe complete system evaluations that are performed during testing and balancing efforts or sophisticated measurement techniques that are used in ventilation research. The manual is written for technically competent indoor air quality investigators, building operators and others who need to perform ventilation assessments in order to address existing problems or as part of preventive maintenance programs. The manual provides background information on building ventilation, discusses instrumentation used in ventilation assessments, describes measurement techniques for determining the values of key ventilation performance parameters, and presents procedures to evaluate building ventilation using these techniques.
KEYWORDS Mechanical ventilation, commercial building, indoor air quality.

#NO 7726 Computerized method for balancing ventilation systems
AUTHOR Larsen B T
BIBINF Netherlands, CADDET Energy Efficiency Newsletter, No 2, 1994, pp 23-25, 3 figs #DATE 00:00:1994 in English
ABSTRACT Adequate ventilation with the right amount of air to the right place and at the right time is an important factor in achieving a good indoor climate. Thus it is very important that the ventilation system works properly, which requires reliable pressure loss calculations and a thorough balancing of the duct system. Using today's electronics and computer technology it is possible to do both the calculations and the balance in a cost effective way
KEYWORDS ventilation systems, indoor climate, cost effectiveness

#NO 8369 Good energy economy and indoor climate-conflicting requirements
AUTHOR Seppanen O.
BIBINF France, Ecole Nationale des Travaux Publics de l'Etat, November 1994, proceedings of the European Conference on Energy Performance and Indoor Climate in Buildings, held Lyon, France, 24-26 November 1994, Vol 1, pp243-249.
ABSTRACT Approximately 20% of the primary energy consumption in Finland, about 56 TWh annually, is used for heating residential, office and public buildings. A great potential is seen in conserving energy in buildings. Without proper design and engineering, overhasty decisions saving energy but impairing indoor climate may be made. The expenses of poor indoor climate are not seen as easily as wasteful energy consumption, but they are equal to or more than the expenses of the ventilation of all of the buildings in Finland. However, it is in many ways possible simultaneously both to obtain significant conservation in energy consumption in

the buildings and to improve indoor climate. Such methods include, for example, heat recovery, proper design and control of air flows, balancing of air flows, efficient removing of contaminants, and controlling of local indoor climate.
KEYWORDS energy efficiency, indoor climate, heat recovery

#NO 8676 Duct Design Fundamentals
AUTHOR Brooks P J
BIBINF U S A , Ashrae Journal, April 1995, pp 69-76, 3 figs, 1 tab, 10 refs.
ABSTRACT Describes the basic tools of duct design and some methods that have been used successfully over the years. Generally, the most efficient way to move the air to or from the air movement device (the fan) is by a system of conduits called ductwork. The ductwork must allow the air to move as efficiently as possible so that operating costs are low, objectionable noise is prevented, and duct heat gains and losses are minimized. The ductwork must also be able to withstand internal pressures and contain the air so it is distributed to the proper locations Besides the sizes of duct, the design of the ductwork construction and installation are also important. Such items as space availability, initial cost, balancing, and fire and smoke control must be considered.
KEYWORDS duct, building design, mechanical ventilation, air flow.

#NO 9547 Design criteria of ventilation for healthy buildings.
AUTHOR Seppanen O
BIBINF Healthy Buildings 95, edited by M Maroni, proceedings of a conference held Milan, Italy, 10-14 September 1995, pp 215-238, 10 figs, 6 tabs, 38 refs.
ABSTRACT The purpose of ventilation is to maintain and improve air quality in a building by removing polluted air and supplying fresh air. In principle, the required ventilation rates for desired air quality can be calculated if the pollution loads, outdoor air quality and requested indoor air quality are known. This method is often referred to as an air quality method in ventilation design. A European prestandard Ventilation for Buildings - Design Criteria for the Indoor Environment outlines such a method. The data for the application of the standard is rapidly accumulating through extensive measurements and is soon available for the general application in ventilation design. Because the data are not yet completed for practical use, additional prescriptive requirements and criteria have to be used in the design of ventilation systems. These criteria include such aspects as the selection of ventilation strategy, ventilation rates, balancing of airflows, ventilation effectiveness, local exhaust systems, cleaning of intake air, location of air intakes, cleanliness of equipment, air recirculation, air tightness, noise control and demand controlled ventilation. The reasoning behind these requirements is presented and discussed in the paper.
KEYWORDS building design, health

#NO 9679 Optimal control of duct pressure in HVAC systems.
AUTHOR Li H, Ganesh C, Munoz D R
BIBINF USA, Ashrae Transactions, Vol 102, Pt 2, 1996, [preprint], 8 figs, refs.
ABSTRACT The energy cost of monitoring and controlling a building environment is a serious consideration for the heating, ventilating, and air-conditions (HVAC) engineering industry. This work is focused on minimizing the energy cost associated with the control of variable-air volume (VAV) systems. All the experimental work was performed using a low-speed wind tunnel. The authors modified a low-speed wind tunnel to simulate a single VAV system. We also developed a dynamic model of the system and analyzed its energy consumption characteristics. Conventional proportional and integral (PI) control, adaptive control and optimal control algorithms were developed and applied to the duct pressure control loop within the VAV system. A comparison of the performance of these control algorithms indicates that an optimal control strategy can save up to 30% of the energy consumed in a system that employs a conventional PI control scheme.
KEYWORDS pressurisation, duct, air conditioning

#NO 9901 The Helsinki office environment study: air change in mechanically ventilated buildings.
Teijonsalo J, Jaakkola J J K, Seppanen O
Indoor Air, No 6, 1996, pp 111-117, 5 figs, 3 tabs, refs.
The objective of this study was to assess the magnitude and balance of mechanical ventilation in the rooms of Helsinki metropolitan office building with different types of ventilation systems. A random sample of 50 office buildings was selected from the Building Registry. Of these buildings, the 33 that have a mechanical ventilation system were included this study. Most office buildings in the Helsinki metropolitan area have a ducted supply and exhaust system and hot water radiator heating. Air recirculation is used in about half of the buildings which have a mechanical supply and exhaust system. The average exhaust air=flow was 1.2L/s,m square (SD 0.73) or 17.2l/s per person (SD 11.6) The variation of the airflows was found to be very high among the buildings, and among the rooms within the buildings. Therefore, even though the ventilation rates on average comply with the Finnish building code, it was found that many people were working in offices with airflows which were either too low or unnecessarily high.
office building, air change rate, mechanical ventilation

#NO 10045 A model-based air flow management system.
Pekkinen J, Mattila T, Laurikainen J

Indoor Air '96, proceedings of the 7th International Conference on Indoor Air Quality and Climate, held July 21-26, 1996, Nagoya, Japan, Volume 2, pp 181-183.
A new air flow management system has been developed, which is based on a mathematical model of the ductwork. The model is given as input data in the form of a table. The intelligent control system checks the ductwork and makes an automatic balancing procedure to determine the pressure drops of different ductwork components and branches. Once the control system knows the geometry of the ductwork, it can control the system according to described procedures.
air flow, mathematical modelling

#NO 10855 Checking the performance of ventilation systems.
Anon
Sweden, The Swedish National Board of Housing, Building and Planning, General Guidelines 1992:3E, 30pp.
Describes current requirements concerning compulsory performance checks of ventilation systems as well as the guidelines applied by the Swedish National Board of Housing, Building and Planning in considering applications for national authorization of inspectors.
ventilation performance, building regulations

#NO 10867 Situations to consider when variable air volume is an option.
Kukla M D
USA, Ashrae Transactions, Vol 103, Pt 2, 1997 [preprint].
Variable-air-volume systems utilize some of the latest technology available to control zone temperatures and save fan energy. In fact, the energy savings can be quite substantial. Then why do engineers and building managers have reservations about using this type of system ? Probably the memory of past experiences. The chain of design, equipment selection, installation, and air balancing must be tailored to a building's needs or conflicts will arise. There are many disciplines to consider when creating a VAV system, and if one link is weak, there can be trouble. Are more complicated systems the price we have to pay for saving energy ?
ventilation system

#NO 10976 Guidance and the standard specification for ventilation hygiene.
BSRIA
UK, Building Services Research and Information Association, 1997, 2 booklets.
Describes the processes for conducting a ventilation hygiene contract, from managerial issues through to the technical aspects of cleaning. The guidance is applicable to the health and safety requirements of mechanical ventilation systems, including air conditioning. Covers management of ventilation hygiene, inspection, sampling and testing, level of cleanliness, cleaning methods, high risk extraction systems, disinfection, elimination of odours, cleaning after fire and smoke damage, hazardous materials, waste disposal, fault reporting, the post-cleaning report, and system balance and rebalancing after cleaning.
standard, ventilation system, duct, maintenance

#NO 12420 Alaska craftsman home program. Design and installation manual for residential mechanical ventilation systems.
Anon
Canada, Alaska Craftsman Home Program, Inc (ACHP).
Construction details used to reduce energy consumption and moisture damage to the building structure in modern houses greatly reduce natural air leakage. Without mechanical ventilation, normal activities such as laundry, cooking and showers can cause excessive humidity levels resulting in occupant discomfort, condensation on cool walls and windows and bacterial or fungal growth. There is also a concern with occupant health. Furthermore, as building envelopes become tighter, there is increased competition for air among the various systems, equipment, and appliances. The designer and installer of ventilation systems need to know about mechanical system design and installation guidelines that meet the Canadian standard CSA F326. Heating, Refrigeration and Air Conditions Institute of Canada (HRAI) has developed this manual and training program to provide those involved in the design, installation and inspection of mechanical ventilation systems for residences the training and documentation necessary for them to understand the requirements of and comply with the standard. Chapters cover ventilation; definitions; ventilation and distribution; ventilation system design; ventilation system installation; and system commissioning.
mechanical ventilation, system design

#NO 12724 Ventilation strategies for good indoor air quality and energy efficiency.
Seppanen O
in: USA, ASHRAE, 1999, "IAQ and Energy 98: Using ASHRAE Standards 62 and 90.1", pp 257-276, 9 figs, 5 tabs, refs.
This paper shows that the cost of space conditioning of buildings is in the same order of magnitude as at cost caused by deteriorated indoor air quality. The requirements for good indoor air quality and energy efficiency have often been considered to conflict with each other; however, buildings with low energy consumption in Europe seem to have also a lower rate of building-related symptoms. This indicates the importance of power design and installation and qualified well-trained operational personnel who understand both the requirements for good indoor air quality and energy efficiency. Several strategies for ventilation are described in this paper by which, at

the same level of energy consumption, the indoor air quality is improved or, at the same level of indoor air quality, the energy consumption is reduced. These include the following; proper target and design values of indoor air quality and climate, proper location of fresh air intakes, cleaning of intake air, efficient air distribution in rooms with improved ventilation efficiency, heat recovery from exhaust air, control of ventilation rates by air quality, proper selection and control of airflows, correct balancing of airflows, source control and efficient removal of contaminants, controlling indoor climate locally, and natural ventilation and free cooling
sick building syndrome, ventilation strategy

#NO 12770 Duct systems in large commercial buildings: physical characterization, air leakage, and heat conduction gains.
Fisk W J, Delp W, Diamond R, Dickerhoff D, et al
Energy and Buildings, No 32, 2000, pp 109-119, 5 figs, 4 tabs, 13 refs.
Through field studies in large commercial buildings and reviews of building plans, we investigated the effective leakage areas (ELAs), air-leakage rates, and conduction heat gains of duct systems. Different methods for measuring air-leakage rates were also compared. ELAs of supply ducts ranged from 0.4 to 2.0cm2 per square metre of floor area served, and from 1.0 to 4.8cm2 per square metre of duct surface area. On a per-unit-floor-area basis, these duct ELAs are comparable to the values measured in residences. The corresponding values of duct leakage class were 60 to 270, much higher than the range of 3 to 12 reported by ASHRAE [ASHRAE standard 111 - 1988, Practices for Measurement, Testing, Adjusting, and Balancing of Building Heating, Ventilation, Air Conditioning, and Refrigeration Systems, American Society of Heating, Refrigerating, and Air Conditioning Engineers, Atlanta, 1988] as attainable for quality duct construction and sealing practices when leakage at connections to duct-mounted equipment is not considered. The measured air-leakage rates as a percentage of the inlet air flow rate varied from 0% to 30%, with most of the measurements falling between 10% and 20%. Large inconsistencies among the air-leakage rates determined measurement procedures exemplifying the need for further development and evaluation of measurement methods. Heat gains between the outlet of the cooling coils and the supply registers caused supply air temperatures to increase, on average, by 0.6oC to 2oC. The corresponding values of conduction effectiveness were 0.75 to 0.90; thus, heat conduction decreased the cooling capacity of the supply air existing registers by 10% to 25%. Because these results are based on studies in only a few building, generalizations from these findings are premature.
duct system, commercial building, effective leakage area, air-leakage rate

Balancing air flow in ventilating duct systems.
Author :Harrison:E., Gibbard:N:C.,
Source :(Journal of Institution of Heating & Ventilating Engineers,) October 1965, vol. 33, 201-225, Discussion February 1966, vol. 33, 348-362.
ISBN no :
Presents a proportional balancing procedure for a ventilation system, to ensure each outlet supplies or extracts its proper quantity. Describes methods, organisation, instrumentation
and recording of results. Discusses the accuracy required and attainable in ordinary practice. The main discussion is related to low- velocity systems, but the extension of the method to
high-velocity induction systems is also covered. Deals with aspects of design to facilitate the regulation of systems.

#13494 Testing and balancing for the 1990s
Author :Lawson:C:N., Gerdon:R:W.
Source :(ASHRAE Trans.) 1994, Vol.100, Part 1, Paper number NO 94 4 3, 720 724.
ISBN no :
Until the late 1950s, virtually no firms specialised exclusively in testing, adjusting, and balancing the components of heating, ventilating, and air conditioning (HVAC) systems. The
balancing, if performed at all, was done by the HVAC contractor, who lacked the necessary expertise required for advanced testing and balancing. After installation, many design
engineers found that their systems were not working, not because of flawed design but because of improper balancing or deficient performance of the equipment. As a result,
independent rating associations were founded by reputable members of the industry to standardise fan testing methods and develop better field testing procedures. The need for
independent testing and balancing companies also became apparent.

#13495 Specifying commissioning for HVAC systems
Author :Gupton:G:W.
Source :(Aust.Refrig.Air Condit.Heat.) February 1988, 41,44-45, 47-52.
ISBN no :
Provides guidance for planning and specifying commissioning work for HVAC systems, including the cleaning and identification of equipment and piping, cleaning and degreasing piping
systems, chemical treatment programme, lubrication, graphic operating instructions, operating and maintenance manuals, control system checkout, preparation for testing and balancing
and instruction of operating and maintenance personnel.

#13496 The commissioning process - how it affects the building owner and maintenance contractor
Author :Underwood:T:D.
Source :(ASHRAE Trans.,) 1993, vol.99, part 1,

paper number CH-93-5-3, 863- 866, 3 refs.
ISBN no :
Discusses the effects of the commissioning process on the long-term operations and maintenance of heating, ventilation and air conditioning systems in buildings. Deals with the construction process, testing, balancing and controls, documentation and training. Concludes by noting that ASHRAE GPC-1 has produced a commissioning guideline.

#13497 Computerised balancing - garbage in, garbage out
Author :Milewski:L.
Source :(Heat. Pip. Air Condit.,) May 1994, vol.66, no.5, 77-79, 3 figs.
ISBN no :
States there is no doubt that new HVAC systems will be entirely DDC controlled (direct digital control) in one to three years. Discusses what happens to the balancer when you have a job where all the adjustments not only can be entirely can be entirely set from a remote location but often have no means to be adjusted at the zone without specialised gear. States that the balancer has to learn a new technology of controls and will have to invest in some specialised tools to work with the DDC controls. He is still the final word on how much air is coming out of each diffuser. States the weak link with computerised balancing is the terminal flow sensor's accuracy. Maintains the basic theory of multi-point sensing is flawed, producing in situ errors that can only be detected and corrected by on-site independent confirmation of flows as installed. Provides an example of a system which demonstrates the flawed nature of multi- point averaging sensing. Notes how the flow and velocity formulas can be combined and customised for each terminal in a DDC system.

#13498 The use of slide gate dampers for balancing ventilation systems
Author :Loudermilk:K:J., Crowder:J:W.
Source :(ASHRAE Trans.) 1981, Part 2, 321-332, 7 figs, 3 tabs, 8 refs.
ISBN no :
The intent of this study was to develop and predict the relationship between flow velocity, pressure drop, and the ratio of free area to duct area for slide gate dampers when used in balancing ventilation systems. Through the use of these relationships, a procedure for balancing ventilation and air distribution systems before start-up can be outlined. In addition, a brief study of a total pressure analysis technique for the design of ventilation systems is discussed. Similar curves for other types of orifices used in systems balancing are also presented. The advantages of using total pressure to design ductwork over static pressure methods is discussed, and an example design is performed utilising the slide gate adjustment procedure with a total pressure design system.

#13499 Testing and balancing - energy versus performance
Author :Schulz:F:C.
Source :(Consul.Specif.Engr.) June 1990, vol.7, no.8, 78-84, 5 figs, 1 tab.
ISBN no :
States that arbitrary energy conservation tactics have caused numerous environmental problems in all types of buildings. Notes the forecast oil price rises to 1993, which will virtually assure the success of the testing and adjusting industry. Goes on to discuss deteriorating indoor air quality, the need for radon mitigation, the benefits of building pressurisation.
Maintains it is important to maintain a slightly positive building pressure under all occupancy conditions. Concludes that in the 90s testing and adjusting will assume its role as the most critical phase of mechanical system commissioning. Qualified and certified firms will be called on to fine-tune a variety of complex systems and to resolve an ever-increasing number of environmental problems.

#13500 Air handling design: a balancing act
Author :Gupta R
Source :Consul. Specif. Engr., October 1997, vol.22, no.4, 74-76, 4 figs.
ISBN no :
Notes that one of the biggest challenges faced by specifiers stems from the difficulty of measuring airflow in main ductworks and matching fans to system curves. Engineers must consider testing, adjusting and balancing (TAB) requirements when designing air handling systems. From this standpoint considers fluid flow equations, uniform velocity profile, fan selection based on total pressure, not static pressure, and system-effect factors that can distort results delivered by TAB contractors and imply that fans are not meeting their published ratings.

#13501 HVAC integrated system analysis.
Author :Paschal:W:B., Curry:R., Hammersley:R:J.
Source :(ASHRAE Trans.,) 1987, vol. 93, Part 2, 1221-1231, 4 figs. 8 refs.
ISBN no :
An advancement in HVAC system analysis, which is predicted on the electrical analogy to fluid systems is presented here. An integrated description of a building’s HVAC system and rooms is constructed and may be used to support system testing and balancing, system performance analysis, capacity verification testing, and room interactions. Additional system simulation is useful to assess plant modifications and their impact on HVAC performance. This method is applicable to any facility with a large or complex HVAC system configuration.
These improved techniques will produce a major economy in costs of system balancing and other

testing activities while reducing the overall time required to balance the system.

#13502 What engineers need to know about testing and balancing
Author :Bevirt:W:D.
Source :(ASHRAE Trans.) 1994, Vol.100, Part 1, Paper number NO 94 4 1, 705 714, 3 figs., 6 tabs., 6 refs.
ISBN no :
Although HVAC systems are carefully designed, factors such as job conditions, substituted equipment, variations in workmanship, and changing load conditions created a requirement that the air and hydronic systems had to be tested and balanced in order for the system to operate satisfactorily. Unfortunately, most testing and balancing work was haphazard and poorly executed, creating a need for trained testing, adjusting, and balancing (TAB) personnel who could provide professional and accurate work for the HVAC industry. Sets out what the engineers need to know about testing and balancing, including standards, national recognised programmes, specifications and drawings, award of work, system deficiencies, procedures, test instruments, reports and acceptance. Concludes with questions and answers.

#13503 Performance testing of HVAC systems for air quality
Author :Cohen:T.
Source :(IAQ 95, Practical Engineering for IAQ Conference), ASHRAE, Denver, Colorado, October 1995, Editor Goldman:R:F., 43-45, 1 ref.
ISBN no :1 883413 30 3.
Argues time has come for HVAC industry professionals to develop the methods and procedures to provide for positive ventilation requirements to be established, controlled, and tested for acceptance and certification. These tests will include the design professional, the HVAC contractors, the automatic controls contractor, and the Testing and Balancing (TAB) agency. Addresses the steps involved in the design, construction, and testing of an HVAC system to ensure the delivery of satisfactory IAQ in a facility. The primary emphasis is on four important factors that affect the development of an HVAC system. These guidelines apply to the design of a new HVAC system or the modification of an existing facility - 1) The design professional must include the controls system and the means of proportioning the return air and outdoor air intake (OAI) airflow rates in the design process. 2) The contractor responsible for conducting the acceptance tests should be retained during the design phase of the project so that he or she may provide expertise with regard to the automatic controls and the balance of the airflow and water-flow systems. 3) The interface and cooperation between the automatic controls contractor, the TAB contractor, and the contractor for the acceptance tests should be more comprehensive than current common practice. 4) The contract for the acceptance tests should be made directly with the owner.

#13504 What should the design engineer expect the testing, adjusting and balancing agency to do?
Richardson:G.
(ASHRAE Trans.,) 1994, vol.100, part 1, paper no.NO-94-4-2, 715-719, refs. In English
Discusses guidelines for testing, adjusting and balancing, lists qualifications for the TAB agency and gives an overview of TAB work at various stages of construction.
Heating, ventilation, air conditioning, testing, regulating,

#13505 Owner-procured TAB services
Tomlinson:D:T.
(Heat.Pip.Air Condit.) March 1990, vol.62, no.3, 95-96. in English
Maintain that test and balance (TAB) firms and the services they provide are vital for a HVAC system to operate properly and efficiently. Gives reasons why the owner should contact directly with the TAB firm. Lists the minimum TAB firm qualifications which should be addressed in the TAB specifications and the form the specification should take. Makes recommendations concerning the organisation of the testing and balancing process.
Management, testing, regulating,

#13506 Equal area vs. Log-Tchebycheff
Macferran E L
Heat. Pip. Air Condit., December 1999, vol.71, no.12, 26-31, 3 figs, 5 refs. In English
Describes and compares the equal-area and log-Tchebycheff methods of measuring air flow in rectangular ducts and demonstrates why the latter is superior. Goes on to make recommendations for widening the use of the log-Tchebycheff method throughout the building services industry. States the objective is correct testing and balancing of HVAC designs, with the ultimate goal of proper air distribution, air pressures and indoor air quality in all buildings. Lists AMCA, ANSI/AMCA, ANSI/ASHRAE and ASHRAE publications that endorse the log-Tchebycheff method. States that since the author's firm began using this method, there have been no disputes or claims for additional cost during bidding or after a contract was awarded.. Also there have been no post-construction air flow distribution problems, air pressure problems or air noise problems on any of 80 projects.
Air flow, measuring, ducts, rectangular, accuracy, comparing, heating, ventilation, air conditioning,

#13507 The systematic and random errors of

portable air flow balancing instrumentation with various ventilation system fittings
Foltz:D:F.
(ASHRAE Trans.) June 1984, vol.90, part 2B, 627-644, 6 figs, 3 tabs, 5 refs. In English
Presents and compares the results of a test programme to the errors in field balancing. Five instruments were tested on five different ventilation system fittings. The random errors determined apply to the instrument and its application on various fittings. The results show that each type of fitting requires a laboratory-developed correction factor for use with each instrument with the exception of the collector, which can use a single factor for diffusers. The largest corrections were required for the velometer and deflecting vane anemometers when used on diffusers. All instruments demonstrated precision or random error of plus or minus 1 to 5.5% of reading for 1.5% standard.
Testing, comparing, measuring equipment, measuring, instrumentation, regulating,
anemometers, calculating, accuracy, measuring equipment

#13508 Testing and balancing specifications - a new paradigm
van Dyke:D:L., Koops:P:E.
(Consul. Specif. Engr.,) September 1995, vol.18, no.3, 48-52, 3 figs. In English

States that because of the substantial dependence of testing, adjusting and balancing (TAB) work on temperature controls, giving the controls contractor responsibility to perform TAB work has always made sense. Today, with the increasing complexity of the control equipment and programs it is important also to make certain the control contractor has adequate understanding and resources available to install a high-quality system consistent with the engineer's design intent. Presents guidelines and examples offering ideas that are intended to stimulate further discussion on how to best achieve these ends.
Controls, contractors, testing, regulating, heating, ventilation, buildings, air
conditioning, commissioning

Specifying commissioning for building HVAC systems
Author :Gupton:G:W.
Source :(ASHRAE Trans.) 1986 vol.92, part 2B, 451-460.
ISBN no :
Provides guidance for planning and specifying HVAC systems commissioning work including the cleaning and identification of equipment and piping, cleaning and degreasing piping systems, chemical treatment programme, lubrication, graphic operating instructions, operating and maintenance manuals, control system checkout, preparation for testing and balancing and instruction of operating and maintenance personnel.

9.1 Other Notable References

Parsloe (1998) The commissioning of air systems in buildings
BSRIA Application Guide AG 3/89.2

CIBSE (1996) Air distribution Systems Code A:1996

BSRIA (1991) Commissioning of VAV systems in buildings Application Guide 1/91

Parsloe (1995) Over engineering in Building services – An internation comparison of design and installation methods
BSRIA Technical report TR21/95

ASHRAE Standard 111- 1988
Practices for measurement testing adjusting and balancing building heating ventilation air conditioning and refrigeration systems.

ASHRAE 1999 – Handbook HVAC Applications Chapter 36 Testing adjusting and balancing

HVAC Testing and Balancing Manual
Gladstone and Bevirt
3rd Edition Pub by McGraw Hill 1981
ISBN 0 07 024184-8

HVAC Systems – Testing Adjusting and Balancing
SMACNA
1ST edition 1983

Testing and Balancing HVAC systems Manual
Wendes
1981

AABC Handbook

9.2 Web Pages of Relevant Organisations.

Building Services Research Information

Association (BSRIA)
(http://www.bsria.co.uk/)

American Society of Heating Refrigeration and Air Conditioning Engineers (ASHRAE)
(http://www.ashrae.org/)

Chartered Institution of Building Services Engineers (CIBSE)
(http://www.cibse.org/)

SMACNA
(www.smacna.org)

Associated Air Balance Council (AABC)
(http://www.aabchq.com/)

National Environmental Balancing Bureau (NEBB)
(http://www.nebb.org/)

National Occupational; Health and Safety Commission
(http://www.nohse.gov.au/)

The Air Infiltration and Ventilation Centre was inaugurated through the International Energy Agency and is funded by the following twelve countries:

Belgium, Denmark, Finland, France, Germany, Greece, Netherlands, New Zealand, Norway, Sweden, United Kingdom and United States of America.

The Centre provides technical support in air infiltration and ventilation research and application. The aim is to provide an understanding of the complex behaviour of the air flow in buildings and to advance the effective application of associated energy saving measures in both the design of new buildings and the improvement of the existing building stock.

Air Infiltration and Ventilation Centre
Operating Agent and Management
INIVE EEIG
Boulevard Poincaré 79
B-1060 Brussels
Belgium

www.aivc.org
airvent@aivc.org

Tel: +32 2 529 81 00
Fax: +32 2 529 81 10
inive@bbri.be
www.inive.org

Order Code for this publication: BIB11