DEMAND-CONTROLLED VENTILATION - REQUIREMENTS AND CONTROL STRATEGIES

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ABSTRACT

Most standards for air handling systems prescribe a minimum air flow rate per person per hour based on full occupancy of the ventilated space. The number of occupants may fluctuate widely, however, and demand-controlled ventilation (DCV) responds to the actual demand for air renewal. There are now sensors capable of detecting this demand, and these are a prerequisite for DCV and good air quality. Key features of DCV are the incorporation of thermal tolerance bands (heating/cooling, humidification/dehumidification), and special control strategies to reduce or even disable the air flow rate. The benefits are a reduction in running costs and automatic maintenance of indoor comfort whatever the operating conditions.

KEYWORDS

Demand control, Air quality, Standards, Energy

INTRODUCTION

The minimum volume of outside air for an air handling system is usually designed to provide a specified outside air flow rate per person per hour (Fig. 1). This is normally based on a fully occupied space (nominal load). However, experience shows that it is the exception rather than the rule for a space to be occupied by the number of people assumed at the design stage. In most spaces, the level of occupancy fluctuates substantially both over the course of the day and from day to day. During periods of reduced occupancy, the mechanical ventilation system could temporarily be operated at a lower fan stage or reduced fan speed (or even switched off) without any perceptible reduction in air quality. Operating the system in this way, on the basis of demand, can save a significant amount of energy normally used for the distribution and conditioning of the indoor air.

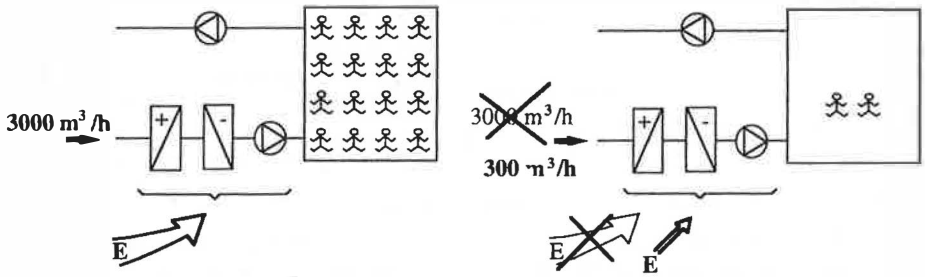

Fig. 1 The outside air flow rate for an air handling system is normally designed for maximum occupancy. For a more rational use of energy, the outside air flow rate needs to be reduced in rooms which are not fully occupied. The most energy-efficient solution is a DCV system with mixed-gas and/or CO_2-sensors for the reference variable.

It should be noted at this point, however, that making rational use of energy does not mean saving energy at all costs! There is a direct relationship between air quality and the general comfort of the occupants of a space. And energy costs are generally quite low in comparison with staff pay or the cost of unfinished work. The aim of a DCV system is to maintain good indoor air quality during normal occupancy hours (provided the space is occupied). In an only partially-occupied space, however, the ventilation can be reduced.

Tab. 1	Suitable applications:	Generally, any space with:
	- Restaurants and canteens	- Fluctuating levels of occupancy,
	- Lecture halls, schools	- An independent ventilation or air conditioning system
	- Shopping malls and department stores	
	- Conference centres and sports halls	
	- Reception halls, booking halls, banking floors, airport check-in desks	
	- Assembly halls, conference rooms, theatres, cinemas	
	- Hotels, residential buildings	

PRINCIPLE OF DEMAND-CONTROLLED VENTILATION

A DCV system is one in which the existing thermal comfort control system is supplemented by a control loop to influence the indoor air quality (Fig. 2). The air renewal demand is continuously assessed by an air quality evaluator and converted into an outside-air demand signal.

The ideal air quality evaluator assesses the quality of the indoor air as it would be perceived by a person on first entering the space. The currently available air quality evaluators process the signals from mixed-gas and/or CO_2 sensors.

However, simply adding an air quality control loop does not make a DCV system. Another highly significant feature is that time-switch control is replaced by a number of demand switches (Fig. 3) responsible for enabling the system. During the potential occupancy hours defined by the time programme, the air handling system switches on only in the event of a measured demand (a demand for heating or cooling, air renewal, humidification or dehumidification etc.). The demand switches are described in detail in the section headed "Control strategy".

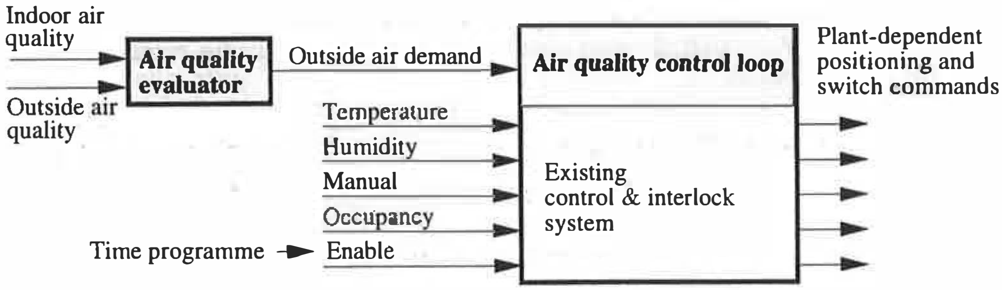

Fig. 2 Principle of demand-controlled ventilation (DCV):

- The existing thermal comfort control system is supplemented by an air quality control loop. This has a predefined effect on the outside air flow rate (variable fan-speed control, fans stages or steps, modulating or open/close dampers, windows, grilles etc., adjustable air cleansing systems).
- The air renewal requirement is continuously assessed by an air quality evaluator, and converted into an outside-air demand signal. The currently available evaluators process the signals from mixed-gas and/or CO_2 sensors. For terms, requirements and tests, see VDMA Standard 24 772: "Sensors for the measurement of indoor air quality".
- Instead of time-switch control, the system starts in response to demand switches (Fig. 3)
- Since the plant itself remains unchanged, existing systems are easy to upgrade.

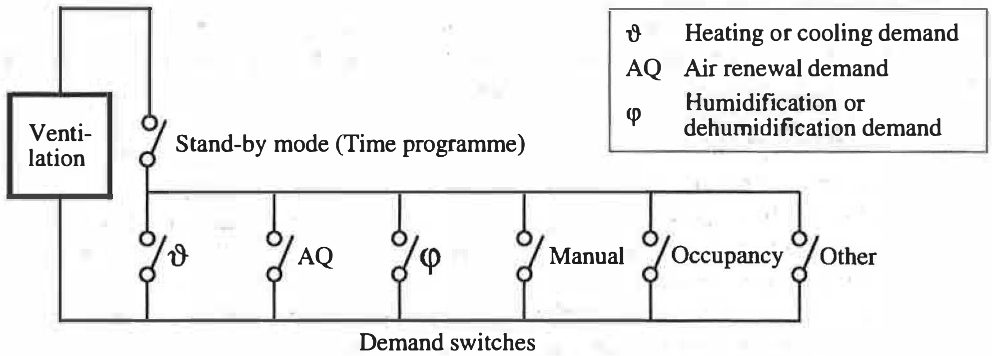

Fig. 3 In stand-by periods, the system is started on the basis of demand switches:

- When the time switch enables the air handling system, the plant does not immediately start running. Instead, it switches to stand-by mode, and will not actually start operation until a demand is registered (details, see Fig. 5).
- Frost protection features and the monitoring of minimum or maximum temperature or humidity limits remain in constant operation.
- For reasons of air hygiene and health, it may be advisable in new or refurbished buildings to operate the system additionally outside normal occupancy times for an initial period, to accelerate the removal of undesirable emissions from new fabrics and furnishings.

CONTROL STRATEGY

The principles for the control of a demand-controlled air handling system are illustrated with an example of a partial air conditioning system (heating/cooling and heat recovery). In Figure 4 the system incorporates heat recovery with a plate heat exchanger and in Figure 6 heat recovery with mixed air dampers.

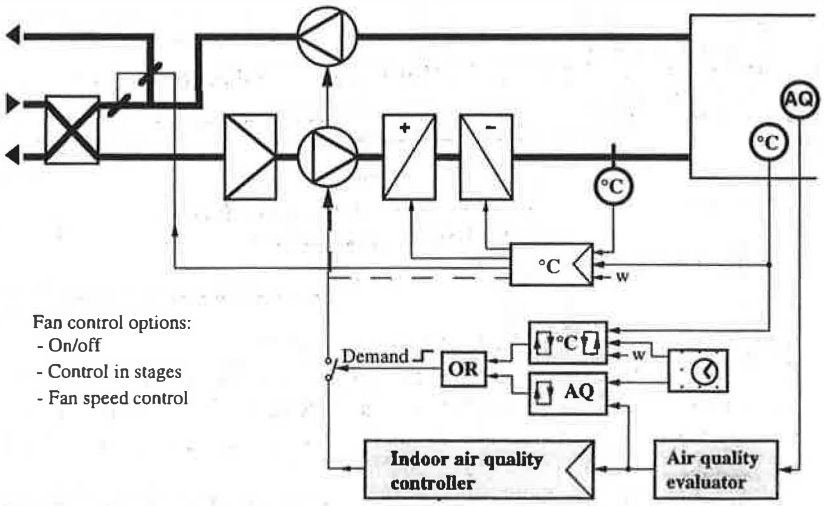

Fig. 4 Practical implementation of DCV based on the example of a partial air conditioning system with heating, cooling and heat recovery with a plate heat exchanger:

- There are no specific requirements in relation to temperature control; as with any normal system, this can be implemented as preferred by the design engineer and building owner.

- Additional requirements: an air quality sensor (for the simplest case) or air quality evaluator (for more complex systems), the demand controller (Fig. 5) and the air quality control loop.
- When the system is enabled by the time switch, the plant does not switch on immediately as it would in a conventional system. Instead it goes into stand-by mode throughout the normal occupancy time defined by the time programme. The system actually switches on when the demand switches (Fig. 5) indicate a demand. The heating or cooling demand and the air renewal demand are weighted equally(logic OR).
- The air quality control loop acts on the fan. This will operate in accordance with the air renewal demand (i.e. switch on/off, from one stage to another or change speed, depending on how the system was designed).

  The control strategies should be so defined that any movement outside the zero-energy band is followed by a return to the zero-energy band. The aim should be to move back towards the middle of the zero-energy band in switch-controlled systems and towards the zero-energy band limits in variable-control systems. Within the zero-energy bands, i.e. in the range in which there is no demand at all, the air handling system should be fully disabled.
- Location of sensors: If the control strategy incorporates the option of a temporary shut-down to achieve maximum energy savings, then the air quality sensor must be located in the room. Placing it close to the extract air outlet generally produces the best results. If a continuous minimum ventilation rate is required during normal occupancy hours, the sensor can, of course, be installed in the return air duct.

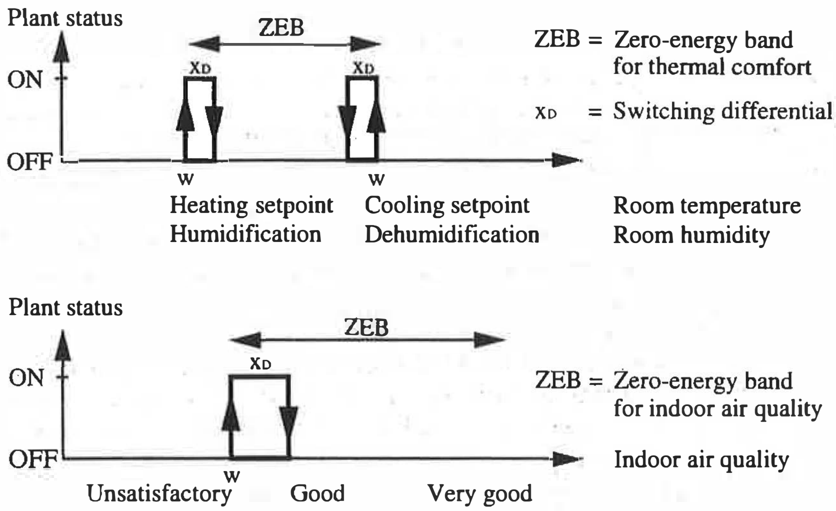

Fig. 5 Demand switches for thermal comfort and air quality:
- If the temperature is below the heating setpoint or above the cooling setpoint, the air handling system will operate irrespective of the air quality.
- If the temperature is within the zero-energy band for thermal comfort, however, the system will operate only if the indoor air quality is unsatisfactory.
- A continuous ventilation rate may be necessary to extract intrinsic pollutants or to maintain static pressure conditions.

- To remove emissions from fabrics and furnishings which accumulate in the indoor air overnight or after several hours of non-use, a boost ventilation period is advisable immediately prior to occupancy.
- The width of the zero-energy band and the switching differential have a significant influence on the number of system starts and the amount of energy saved. Over-frequent plant switching can be prevented by incorporating switch-on delays and a minimum run-time.

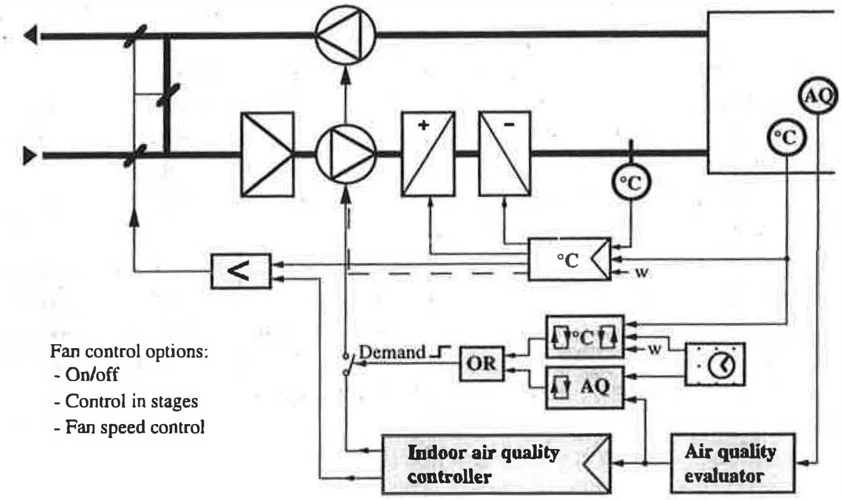

Fig. 6 Practical implementation of DCV based on the example of a partial air conditioning system with heating, cooling and heat recovery with mixed-air dampers:
- In contrast to the system with heat recovery via a plate heat exchanger, the air quality loop in this case acts not only on the fan, but also on the mixed-air dampers.
- Since the cost of distributing the air is far from negligible in comparison with that of heating and cooling, the following control strategy is recommended:
- Whenever possible, the fan should be operated at the minimum flow rate. The proportion of outside air is determined by the temperature <u>and</u> air quality control system.
- Whenever free heating or cooling is available from the outside air, it makes sense to run the system on 100% outside air.
- If the outside air needs to be heated or cooled, the control strategy must be designed to the client's requirements. The recommended approach is one in which the proportion of outside air is determined by either the temperature or the air quality demand, whichever is the greater.
- With deteriorating indoor air quality, the first step should be to reduce the proportion of recirculated air, down to zero. The speed of the fans should not be increased until the system is operating on 100% outside air; if the air renewal demand persists the fans can then be operated up to maximum speed for as long as necessary.
- The remaining principles are as described in Fig. 4.

ECONOMIC EFFICIENCY

Practical implementation of the technology is one thing, but before a specific approach becomes the norm, evidence must be provided of clearly identifiable customer benefits. The nature of these benefits may be material or non-material.

One important, non-material benefit of DCV is that instead of having to attend to the operation of the air handling plant, the system operator can devote time to more important matters, such as the fine-tuning of the overall system. Since the air renewal demand is measured continuously, the plant will switch off automatically if the space is ventilated by open windows or doors. DCV also ensures that rooms are aired after a period of use, preventing odour from being absorbed by the fabrics and furnishings in the room only to be emitted later.

The material benefits of DCV depend on the amount by which the air flow rate to the room can be reduced without impairing thermal comfort and air quality (see Fig. 7).

Empirical values indicating the savings to made are shown in Table 2.

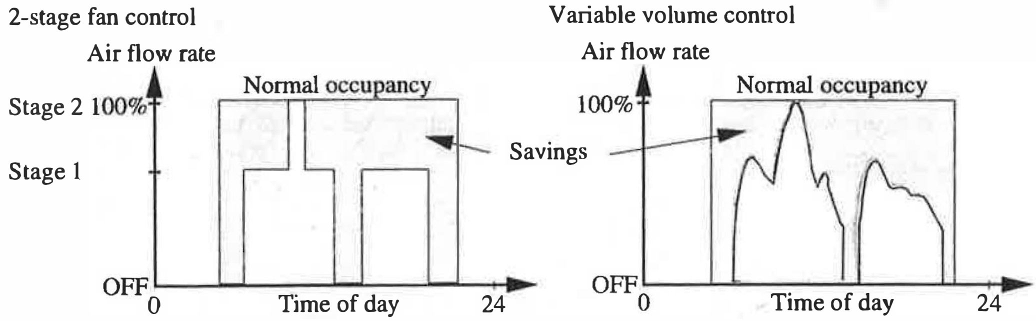

Fig. 7 Savings from a demand-controlled ventilation system (DCV) compared with an air handling system controlled by a time programme.

Tab. 2 Empirical values showing the potential energy-cost savings in typical DCV applications. The values are based on results from the IEA project, Annex 18 "Demand Controlled Ventilating System" (W. Raatschen et al. (1990), Fahlen et al. (1992) and on the experiences of the various control companies:

- Restaurants, canteens		20 - 50 %
- Lecture halls		20 - 50 %
- Open-plan offices	40% of staff present on average	20 - 30 %
	90% of staff present on average	3 - 5 %
- Entrance halls, booking halls, airport check-in areas		20 - 60 %
- Exhibition halls, sports halls		40 -70 %
- Assembly halls, theatres, cinemas		20 - 60 %

ESTIMATED RETURN ON INVESTMENT

In order to quantify the material customer benefits of DCV more precisely, a calculation model was drawn up, based on the constraints and assumptions shown in Table 3. The study is based on a building in the services sector, occupied for 2750 hours per year. The influence of internal heat gains was included in simplified form when calculating the heat demand (18°C supply air temperature, 22°C return air temperature, heat recovery).

Fig. 8 shows the payback period for the additionally invested capital as a function of the system size (air flow rate) and the average reduction in air flow rate achieved.

Tab. 3 Constraints and assumptions for the payback periods shown in Figure 8: The model is based on a comparison between demand-controlled ventilation and an air handling system controlled by a time programme and operating throughout normal occupancy hours at the nominal ventilation rate:

- Nominal ventilation rate	1,000 to 10,000	m^3/h
- Outside air flow rate per person	40	m^3/h per person
- Mean reduction in air flow rate as a result of DCV	20 - 40 - 60	%
- Building occupancy hours	2750	h per year
- Supply air / return air temperature	18 / 22	°C
- Efficiency of heat recovery system	60	%
- Total pressure drop across system at nominal flow rate	1200	Pa
- Heating degree days / Heating days	3000 / 200	HDD / HD
- Capital cost of additional equipment (DCV, new system)	2000	DM
- Electricity costs (kWh rate)	0.20	DM/kWh
- Heat cost	0.07	DM/kWh
- Capital interest	not included	

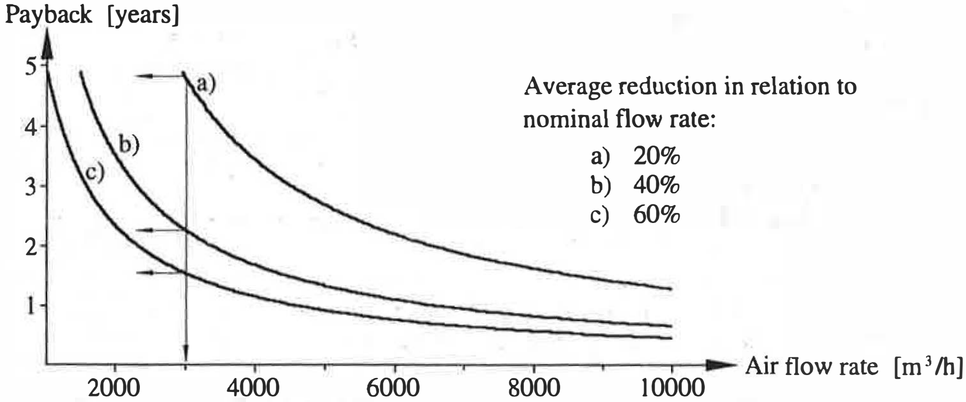

Fig. 8 Payback period as a function of the nominal flow rate and the percentage reduction in flow rate resulting from DCV. The payback period relates to the additional capital invested in DCV over and above the cost of a conventional air handling system:

- The payback period decreases exponentially as the size of the system increases. For systems handling 10,000 m^3/h the payback is typically less than 1 year (mean air flow rate reduced by 40%).
- Neither is there a linear relationship between the payback period and the mean reduction in flow rate achieved. For a system handling 3000 m^3/h with a 20% reduction in volumetric flow, the payback period is 5 years. If the typical value of 40% is achieved, the payback period comes down to 2.2 years. Improving the reduction in flow rate to 60% only shortens the payback period by approximately 0.7 years.
- The calculation clearly demonstrates that systems with nominal flow rates >2000 m^3/h should always incorporate DCV. When the additional non-material benefits are taken into account, even smaller systems merit this approach.
- As stated earlier, there is no difficulty in upgrading existing systems (Fig. 2, 4 and 6).

PREREQUISITES - TYPICAL PRELIMINARY PROCEDURE

The prerequisites for DCV are as follows:

1. There must be a means of controlling the air flow rate according to predefined criteria (fans switched on/off, in stages or variable fan-speed control, modulating or open/close damper control, façade openings, adjustable air cleansing systems etc.).
2. In empty rooms and during periods where there is no measured air renewal demand, there must be a means of disabling the plant, or of reducing the air flow rate to a minimum.

3. For air handling systems incorporating a heating or cooling demand, a zero energy band must be defined (Fig. 5). While the room temperature is within this temperature band, the system will operate only in response to an outside air demand.

Figure 9 illustrates the typical procedure for the introduction of demand-controlled ventilation in new systems, and for modernisation and renovation projects.

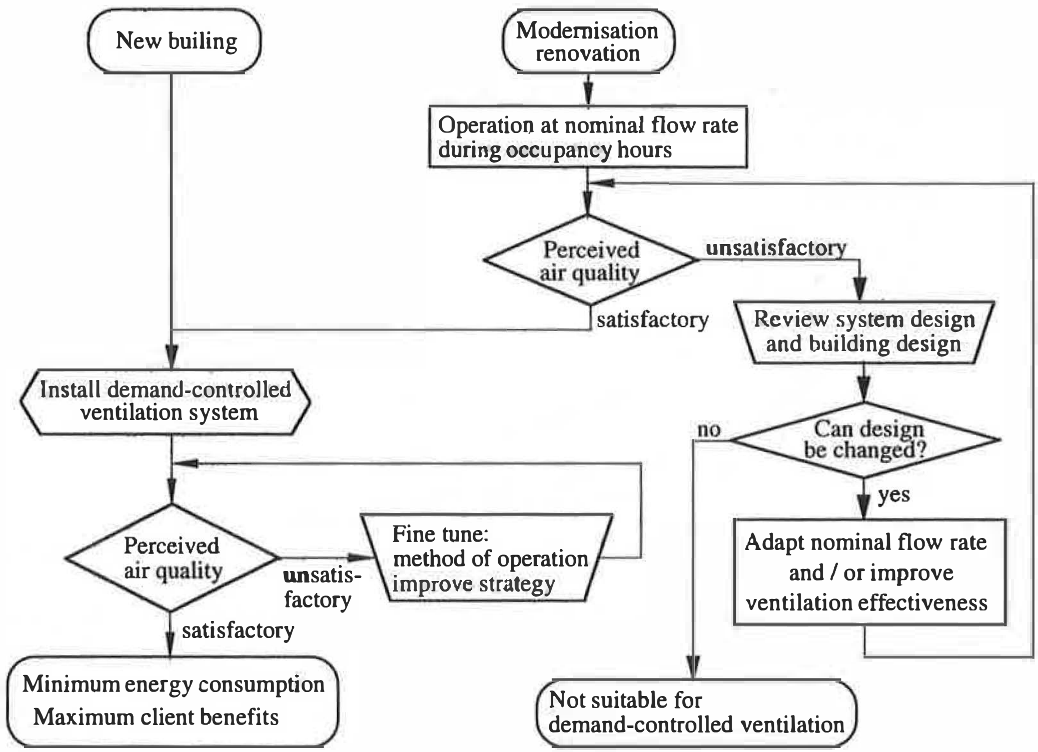

Fig. 9 Typical procedure for the introduction of demand-controlled ventilation in new systems or for modernisation and renovation projects.

ACKNOWLEDGEMENTS

The standard referred to was written within the framework of a VDMA working party consisting of specialists from Belimo, Honeywell, Johnson Controls, Landis & Staefa, LTG, Messner Technik and Sauter without whom none of this work could have been achieved. My thanks also to Marguerite Minster for the excellent translation of the paper.

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