Annex 35

HybVent - Hybrid Ventilation in New and Retrofitted Office Buildings - State of the Art

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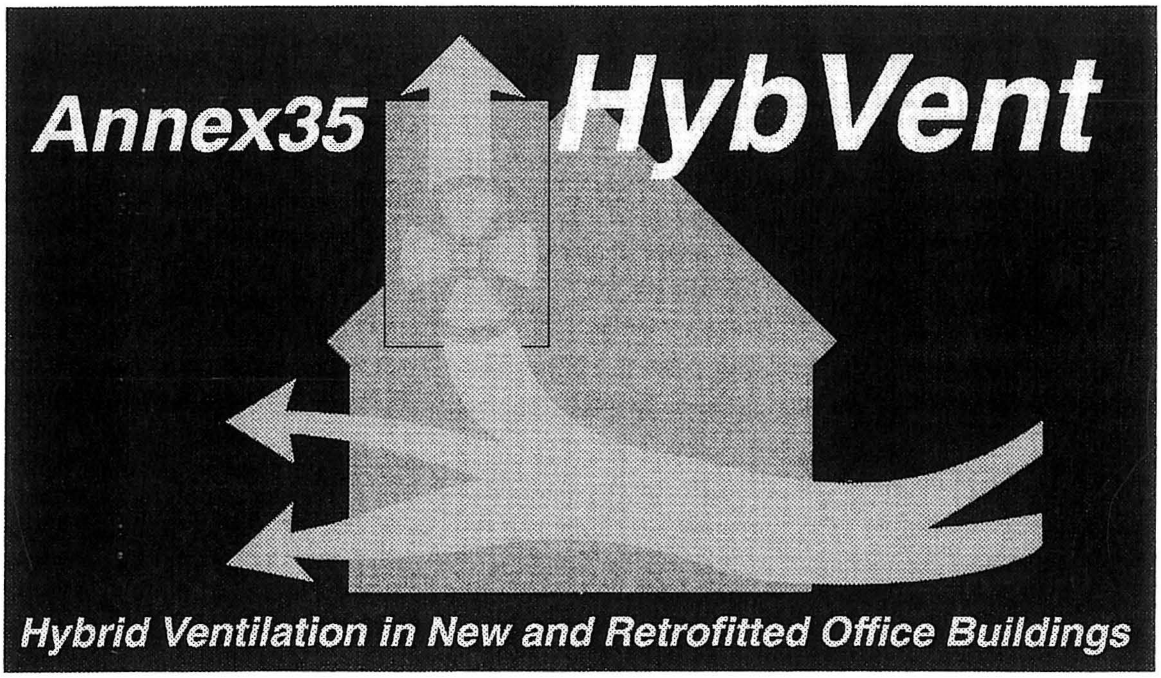

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ANNEX 35
HYBVENT - HYBRID VENTILATION IN NEW AND RETROFITTED OFFICE BUILDINGS.

by

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ANNEX DESCRIPTION

The Annex was initiated in August, 1997 with a preparatory year. The duration of the Annex is four years (August 1, 1998 – July 31, 2002) and the project period is divided into three phases - a fact finding phase, a working phase and a reporting phase.

The Annex has participation from 15 countries, which are: Australia, Belgium, Canada, Denmark, Finland, France, Germany, Greece, Italy, Japan, Norway, Sweden, The Netherlands, United Kingdom and USA. The 15 countries are represented by 30 research groups; 13 from universities, 11 from research institutes and 6 from companies.

Background

Today, in the design of new buildings and retrofit of old buildings an integrated approach is used with focus not only on thermal insulation, airtightness and heat recovery but also on optimal use of sustainable technologies as passive solar gains, passive cooling, daylighting and natural ventilation. Buildings are designed to interact with the outdoor environment and they are utilizing the outdoor environment to create an acceptable indoor environment whenever it is beneficial. The extent to which these sustainable technologies can be utilized depends on outdoor climate, building use, building location and design. Under optimum conditions sustainable technologies will be able to satisfy the demands for heat, light and fresh air. In some cases supplementary mechanical systems will be needed and in other cases it will not be possible to use sustainable technologies at all.

Unfortunately, the design of energy-efficient ventilation systems in buildings has often become a question of using either natural or mechanical ventilation. This has prevented a widespread use of sustainable technologies because a certain performance cannot be guaranteed under all conditions with natural ventilation. In fact in the majority of cases a combination of systems would be beneficial depending on outdoor climate, building design, building use and the main purpose of the ventilation system. The development of sustainable ventilation technologies is far behind other sustainable technologies and there is certainly a need for development of innovative hybrid ventilation systems.

The scope of the annex is to obtain better knowledge of the use of hybrid ventilation technologies. The annex will focus on development of control strategies for hybrid ventilation, on development of methods to predict hybrid ventilation performance in office buildings and on development, implementation and demonstration of hybrid ventilation in real buildings.

Definitions

Hybrid ventilation systems can be described as systems providing a comfortable internal environment using different features of both natural ventilation and mechanical systems at different times of the day or season of the year. It is a ventilation system where mechanical and natural forces are combined in a two mode system. The basic philosophy is to maintain a satisfactory indoor environment by alternating between and combining these two modes to avoid the cost, the energy penalty and the consequential environmental effects of year-round air conditioning. The operating mode varies according to the season and within individual days, thus the current mode reflects the external environment and takes maximum advantage of ambient conditions at any point in time. The main difference between conventional ventilation systems and hybrid systems is the fact that the latter are intelligent with control systems that automatically can switch between natural and mechanical mode in order to minimize the energy consumption.

Hybrid ventilation should dependent on building design, internal loads, natural driving forces, outdoor conditions and season fulfil the immediate demands to the indoor environment in the most energy-efficient manner. The control strategies for hybrid ventilation systems in office buildings should maximize the use of ambient energy with an effective balance between the use of advanced automatic control and the opportunity for users of the building to exercise direct control of their environment. The control strategies should also establish the desired air flow rates and air flow patterns at the lowest energy consumption possible.

Objectives

The objectives of Annex 35 are

- to develop control strategies for hybrid ventilation systems in new build and retrofit of office and educational buildings
- to develop methods to predict hybrid ventilation performance in hybrid ventilated buildings
- to promote energy and cost-effective hybrid ventilation systems in office and educational buildings
- to select suitable measurement techniques for diagnostic purposes to be used in buildings ventilated by hybrid ventilation systems

Means

Three subtasks will be carried out in order to reach the objectives:

Subtask A: Development of control strategies for hybrid ventilation

Subtask B: Theoretical and experimental studies of performance of hybrid ventilation. Development of analysis methods for hybrid ventilation

Subtask C: Pilot studies of hybrid ventilation

Subtask A: Development of Control Strategies for Hybrid Ventilation

A hybrid ventilation system, which is integrating both natural and mechanical driving forces in the same ventilation system, requires development of new control strategies. These strategies should ensure at any time and for a certain combination of internal loads, outdoor conditions and comfort requirements that the immediate demands to the indoor environment are fulfilled in the most energy efficient manner. As the function of hybrid ventilation is closely related to the use and function of the building a thorough control of hybrid ventilation requires a completely integrated approach where building design, its technical systems (lighting, heating), occupant behaviour, surroundings, climatic and meteorological conditions etc., are taken into consideration.

The participants will as a starting point take a typical case in their own country and climate and by theoretical studies, laboratory experiments and field studies of the performance of different control strategies in a hybrid ventilated building develop the most suitable strategies. The main focus will be on development of strategies for switching between ventilation modes and for combining central automatic and individual manual control.

The cost-effectiveness of different ventilation and control strategies are investigated by comparing capital cost and operational costs against a typical refurbishment or new building. Assessment philosophies and analysis methods of hybrid ventilation concepts are developed in the framework of Energy Performance Standardisation Regulations.

Subtask B: Theoretical and experimental studies of performance of hybrid ventilation. Development of analysis methods for hybrid ventilation

Thorough understanding of the hybrid ventilation process is a prerequisite for a successful application of hybrid ventilation, for development of optimum control strategies and for development of analysis methods for hybrid ventilation design. The annex will therefore by theoretical and experimental studies investigate the different elements of the air flow process in hybrid ventilation from air flow around buildings, air flow through openings, air flow in rooms to air flow between rooms in a building. The hybrid ventilation process is very dependent on the outdoor climate as well as the thermal behaviour of the building and therefore, it is essential to take these factors into consideration.

Suitable analysis methods as we know them for mechanical systems are not available for hybrid ventilation systems. Valid methods would give architects and engineers the necessary confidence in system performance, which in many cases, is the decisive factor for choice of system design.

As the hybrid ventilation process and the thermal behaviour of the building are linked the development of analysis methods for hybrid ventilation must take both aspects into consideration at the same time and include efficient iteration schemes. This is the case for all types of analysis methods from simple analytical methods, zonal and multizone methods to detailed CFD analysis methods. The subtask will deal with methods on different levels, but a major focus will be on combining thermal simulation models with existing multizone air flow models. In this way the thermal dynamics of the building can be taken into account and this will improve the prediction of the performance of hybrid ventilation considerably. The combined model will be the most important design tool for hybrid ventilation.

Subtask C: Pilot Studies of Hybrid Ventilation

Pilot studies in different countries are used to implement hybrid ventilation systems and demonstrate their performance. Buildings with hybrid ventilation often include other sustainable technologies like daylightning, passive cooling, passive solar gains etc, and an integrated approach is often used in the design of the building and its technical systems.

The pilot studies are monitored to collect data on performance (IAQ, thermal comfort and energy consumption) and to evaluate corresponding control strategies and analysis methods. The pilot studies include both retrofitted and new build designs and highlight similarities and differences in climatic issues (including seasonal differences), institutional and cultural issues (developers and occupants), and technology transfer issues. The pilot studies concentrate on success stories of hybrid ventilation but also critically highlight problematic cases.

STATE-OF-THE-ART REVIEW

The first goal of the annex has been to provide a state-of-the-art review of hybrid ventilation. This review has included a survey of existing buildings and systems in the participating countries together with a survey of commercially available components and a survey of building codes and standards and their impact on application of hybrid ventilation to highlight barriers to, or opportunities for implementation.

The report describes the state-of-the-art in hybrid ventilation technologies, control strategies and algorithms, and analysis methods. The main focus is on the advantages and disadvantages of methods, tools, systems and components. The review identifies weaknesses and lack of knowledge in system performance, components, control strategies and design methods, and identifies and prioritises research needs. It provides examples of systems installed in existing buildings, showing solutions to specific problems (fresh air supply, excess heat removal, etc.), in office buildings located in different outdoor climates. The intended audience is both the participants and the design community. The starting point is existing buildings. The following is a short summary of the main findings and conclusions.

Expectations of Hybrid Ventilation in the Participating Countries

The 15 countries participating in Annex 35 are doing so because experts in each country believe that hybrid ventilation offers significant opportunities for improving the indoor environment and reducing energy demand. Naturally, because of climate variations and other factors, different countries have differing expectations of HV. Each participating country prepared a short description of their expectations of HV. Table 1 summarises the key issues arising from these descriptions. Commonly-cited statements were that hybrid ventilation systems are expected to:

- Offer a wider range of design options
- Reduce noise from fans
- Reduce electricity demand
- Reduce energy demand
- Reduce CO_2 emissions
- Allow more individual control, operable windows, etc.
- Deliver satisfactory or even improved IAQ.

Table 1. Expectations of hybrid ventilation (HV systems are expected to ....)

country/issue		Australia	Belgium	Canada	Denmark	Finland	France	Germany	Greece	Holland	Italy	Japan	Norway	Sweden	UK	US
system	be a simpler and more robust system												x	x		
	be a compromise between an uncontrolled indoor environment and a mechanical system						x				x		x			
	allow the combined use of intelligent mechanical ventilation for IAQ control and a combination of natural and mechanical ventilation for summer comfort control		x													
	be especially attractive in combination with natural lighting, atriums and double façades					x							x			
	offer a wider range of design options					x				x			x	x	x	
	satisfy customers requirements					x								x		
health and well-being	reduce noise from fans					x							x	x		
	satisfactory thermal comfort (i.e. preheating of supply air)		x			x							x			
	improve IAQ in periods with abundant natural forces		x		x											
	improve IAQ		x							x			x			
	satisfactory IAQ (filtering, etc.)					x								x		
	increased focus at demand controlled ventilation		x			x							x			
	simpler to keep clean												x			
	reduce the sick building syndrome problem	x	x										x			
	offer physiological and psychological benefits for the user							x								
	feeling of natural ventilation					x										
	increase occupants' satisfaction	x	x			x							x			
	deliver more efficient ventilation		x						x							
cost and environ-ment	reduce electricity demand				x	x					x		x	x		x
	eliminate mechanical cooling demand				x											
	reduce mechanical cooling demand		x										x			
	practically eliminate air conditioning demand during intermediate seasons		x						x							
	reduce demanded mechanical air conditioning operation time significantly								x							
	reduce need for mechanical air conditioning		x						x							
	reduce energy demand	x	x				x	x		x		x				
	offer competitive total heat energy demand		x										x			
	offer competitive exhaust air heat recovery					x										
	shorten investment payback period	x	x													
	reduce maintenance costs												x			
	improve occupants' productivity	x											x			
	increase property values due to improved indoor environment quality	x														
	need less maintenance					x						x	x			
	offer longer system lifetime												x			
	reduce CO_2-emissions	x					x				x	x				
usability	allow more individual control, operable windows, etc.	x	x			x						x	x			
	be simpler to maintain					x						x	x			
	be simpler to use					x						x	x			

Survey of Existing Buildings

Quite a number of hybrid-ventilated buildings have already been built around the world, and more are planned or about to be built. The survey includes 22 existing buildings from ten of the countries participating in this Annex. Particular topics of interest in this survey were the overall design philosophy used to ensure good IAQ and thermal comfort, the control strategies used, and the components used.

It is clear from the descriptions of the overall design philosophy that a successful hybrid ventilation design depends on an integrated approach, in which optimal use is made of sustainable technologies such as passive solar gains, daylighting and natural ventilation. In particular it requires good thermal design, and in a number of buildings thermal mass combined with intensive night ventilation (using natural forces or fan assistance) is exploited to stabilise temperatures during the day.

The buildings surveyed are low to medium-rise buildings (except for the Meiji University Tower in Tokyo), located in areas with little or moderate dust and noise pollution. Further examples of high-rise hybrid-ventilated buildings, or buildings in more challenging environments, will be useful to demonstrate that innovative solutions can be found for a wide variety of applications and environments.

Control strategies in the buildings surveyed are usually based on temperature control, with some (particularly schools) also using CO_2 control. Both manual and automatic control of openings and fans is often available. More information is needed on how well the control strategies work in practice, whether there are any reliability problems with motorised openings, and similar issues.

Some basic components were used in most buildings. These include fans, CO_2 and temperature sensors, manually operated and/or motorised windows or special ventilation openings, and wind towers, solar chimneys or atria for exhaust. Six buildings used underground ducts, culverts or plenums to pre-condition the supply air.

Some of the buildings surveyed have been successfully retrofitted with hybrid systems. Many existing office buildings either overheat in summer or use excessive amounts of energy to maintain acceptable temperatures, because of increasing internal heat gains from office equipment, low-efficiency lighting systems, high staff densities, and excessive solar gains. When refurbishment is due in these problem buildings, new air conditioning systems are installed to either replace a natural ventilation system or an existing air conditioning system. Thus retrofitting hybrid ventilation systems in existing buildings when they are due for refurbishment has the potential to greatly increase the impact of this technology on energy consumption and worker satisfaction and productivity.

Critical Barriers to Hybrid Ventilation

Hybrid ventilated buildings must comply with existing building codes and standards, where they are mandatory. A survey in twelve of the countries participating in Annex 35 describes the paragraphs in acts, codes, standards or recommendations that may have an impact, positive or negative, on hybrid ventilation systems. The key issues relate to indoor air quality and thermal comfort, energy performance, acoustics, and fire and safety.

In general, none of the countries surveyed have regulations that severely restrict the general use of natural or hybrid ventilation. Some paragraphs recommend or require mechanical ventilation in special cases, for example in polluted urban areas and when radon is present in the ground. Some countries have high requirements for air flow rates, which will imply a high demand for fan power. Hybrid ventilation systems rely as much as possible on natural driving forces, although in practice they may have more or less fan power installed than mechanical systems. Thus while a requirement for high air flow rates will not necessarily favour a pure mechanical system over a hybrid system, it is not in line with the HV approach.

Three countries recommend a CO_2-level less than 1000 ppm, which may require extensive use of fans. In areas with low pollution loads this may imply a higher fan power demand than necessary. In the five countries where heat recovery is required, this may imply an unnecessary high fan power demand, for example when using an underground supply air duct.

There are requirements on minimum temperatures and summer maximum temperatures, but these are mostly non-mandatory. Most countries have requirements on maximum noise levels in indoor spaces and noise generated by plant or duct systems. In addition Italy, Norway and Sweden have requirements on the acoustic insulation of façades, which may be of concern for hybrid systems since they may require façade openings.

Fire, smoke and noise regulations probably represent the most serious barriers to hybrid ventilation. Paragraphs on these issues, most of them mandatory, were found in all the countries. The more open nature of buildings with hybrid ventilation systems tends to enhance the spread of smoke and fire. Hybrid ventilation systems therefore will need careful design to meet requirements on openings, compartmentation and smoke removal. However, it should be emphasised that it is often possible to satisfy fire regulations if compensatory measures such as sprinkler systems are used.

Not all the requirements in codes and standards represent a barrier. Requirements that deal with restricting electricity use, noise generated by installations and access to ducts for cleaning may favour hybrid ventilation over mechanical ventilation systems.

It is likely that almost none of the paragraphs found in the survey were written with the possibility of combining natural and mechanical ventilation in mind. The absence of such regulations and recommendations will cause uncertainty among designers and building developers, and could thus be seen as a barrier to hybrid ventilation.

Notwithstanding the barriers or challenges that may exist, it is worth emphasising that none have prevented a wide variety of hybrid-ventilated buildings being built and planned.

Barriers to natural ventilation systems have been investigated in previous projects, in particular the AIOLOS project (Allard, 1998) and the NatVent project (Aggerholm, 1998a, 1998b). Table 2 gives a broad overview of barriers identified in AIOLOS, Nat**Vent**^{TM}, and in HybVent to date, which may hinder the use of hybrid ventilation systems.

Table 3.1. Some identified barriers to natural and hybrid ventilation

Type of barrier		Barrier	Source
Design	Economy	Designers' fee depends on investment cost of ventilation components	AIOLOS
		Fear of increased costs for designers	HybVent
		Designers' fear of not succeeding	HybVent
		Fear of increased space demand	HybVent
		Fear of increased overall investment costs	HybVent
	Knowledge	Uncertainty due to lack of information, knowledge and experience about hybrid ventilation and lack of examples of documented and successful hybrid ventilated buildings	NatVent/ HybVent
	Regulations, guidelines and tools	Reduced number of design options for ventilation system and increased investment costs due to fire compartmentation and noise regulations	AIOLOS/ HybVent
		Uncertainty among designers due to lack of suitable design tools	AIOLOS/ NatVent
		Uncertainty due to lack of suitable standards and regulations	AIOLOS
	Architecture	Fear of the impact of chimneys, towers, building envelope, etc. on the architecture and overall design	AIOLOS
	Unwillingness	Smart control devices which may overcome other barriers are not being implemented due to unwillingness among building owners or promoters	AIOLOS
Use	IAQ and thermal comfort	Fear of ventilation short-circuits	HybVent
		Risk of obstructed airflow through windows due to shading devices for solar control or privacy	AIOLOS
		Fear of unsatisfactory IAQ and thermal comfort	HybVent
		Lack of acceptance of fluctuations in indoor climate conditions (high summer temperatures, temperature variations during the day, temperature differences between floor and ceiling, etc.)	AIOLOS
		Risk of draught from ventilation openings in façade	AIOLOS
		Risk of decreased IAQ and thermal comfort because users do not know how to operate the system correctly	AIOLOS
		Risk of polluted supply air due to road traffic, industry, pollen, etc. when filtering is not used	AIOLOS
	Safety	Risk of intrusion of unwanted elements through openings, i.e. burglars, animals, insects or precipitation.	AIOLOS
		Fear of fire and smoke distribution through airflow paths	HybVent
	Noise	Fear of noise distribution through façade and between rooms within the building	AIOLOS/ HybVent
	Useability	Fear of increased user effort to maintain IAQ and thermal comfort	HybVent
	Economy	Fear of increased overall energy demand (due to less effective heat recovery)	HybVent
		Risk of increased fan power demand due to fire protection and noise distribution regulations	HybVent

Control Strategies for Hybrid Ventilation

The complexity of a control strategy for HV depends on the major purpose of the ventilation system. If the major purpose is to provide good IAQ, then the air flow rate must be optimised to balance energy and IAQ considerations, and advanced control strategies are very important. If, however, the major purpose of HV is to provide summer temperature control, optimisation is not as important and simpler control strategies are possible.

In a control system, control and controlled parameters must be chosen with regard to the strategy to be implemented as well as feasibility and cost. Various parameters may be measured, depending on the objectives of the control strategy. These include thermal comfort parameters to allow calculation of PMV, ET, etc, IAQ indicators such as CO_2, CO, H_2O or occupancy, and energy-related parameters to ensure that HVAC system operates efficiently.

Many control techniques have been developed over the past 50 years. They can be classified into three main types: classical; optimal and predictive control; and advanced strategies.

Classical techniques are relatively simple but suffer from a number of limitations, including inability to control more than one parameter, lack of systematic methods for optimally combining techniques, and sensitivity to external disturbances. Optimal and predictive control techniques overcome some of these limitations but have not been developed at an industrial level.

Advanced strategies include the use of fuzzy logic. This makes provision for incorporating expert knowledge of the controlled system and is suitable for the management of imprecise parameters (such as comfort indices) and the incorporation of more than one control parameter. Although examples of fuzzy controller implementations have already been seen in building control, these have usually focused on simple problems, and manual parameter setting requires a long period (months). Simulation data from detailed analysis tools such as ESP, TRNSYS, or DOE2 could be efficiently used for off-line development of fuzzy control rules. Genetic Algorithms are particularly suitable for providing solutions to complex optimisation problems.

A hybrid ventilation control system must be able to control the mechanical (e.g. fans) as well as the natural ventilation components of the system (e.g. windows or other apertures, special inlets). Other components may also need to be controlled to ensure satisfactory thermal performance, for example shading devices or lighting.

The study of control strategies for hybrid ventilation is complex. Many control techniques may be applied to hybrid ventilation buildings, from On-Off control to advanced strategies based on logical programming or fuzzy logic. The switching strategy is a key point for the overall efficiency of the system. Very few examples exist of such hybrid ventilation controllers and there is a lack of feedback on the behaviour of existing systems.

Analysis Tools for Hybrid Ventilation

There are very few, if any, tools available that have been specifically developed for analysing hybrid systems. Several methods are available that can be used to analyse mechanical or natural ventilation systems. These range from simple analytical and empirical methods, multi-zone methods, zonal methods, through to CFD methods. Each has their own area of applicability, e.g. conceptual design, preliminary design, detailed design, or system performance evaluation. Multi-zone methods probably offer the best prospect of a balance between computational efficiency and accuracy.

In fact, the existing building survey revealed that only a few buildings used any kind of design tool, much less one designed for hybrid ventilation systems.

Because hybrid systems combine natural and mechanical ventilation, they present several complex challenges to analysis tools, requiring a global approach that takes into account the outdoor environment, the indoor environment, and the mechanical system. For example, control systems developed for hybrid systems will switch between a natural ventilation mode, which may result in stratified temperatures in the space, to a mechanical mode with mixed air and no stratification. The analysis tool must be able to deal with these mode switches, and it must also be able to model the (possibly complex) control strategy itself. Furthermore, because hybrid ventilation systems are often used for temperature control as well as for IAQ control, analysis tools must be able to integrate thermal modelling with ventilation modelling. Some integrated tools of this type are already available, but further work is needed to model the mutual interaction of thermal stratification and natural and mechanical air flow rates. There are also several outstanding problems in modelling natural ventilation that will need to be addressed:

- Developing reliable methods for estimating wind pressure coefficients for complex buildings
- Understanding wind-driven flows through large openings, in particular the validity of using wind-pressure coefficients obtained for solid surfaces
- Developing better data, e.g. discharge coefficients and component flow characteristics. As new specifically-designed components become available, their performance characteristics will need to be known.

Finally, to increase confidence in the use of hybrid ventilation analysis tools and methods, it will be necessary to develop benchmark problems and solutions to enable the evaluation of these analysis tools.

ANNEX 35 WEB – SITE

All information about the annex is available on the Annex 35 Web-site (http://hybvent.civil.auc.dk). This web site contains description of the annex, papers and publications, information about pilot studies and monitoring programmes as well as measurement and analysis results.

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