APPLICATION OF ICT SUPPORTED LEARNING IN FLUID MECHANICS

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SUMMARY: *This paper focuses on the application of ICT, Information & Communication Technology, supported learning in the area of fluid mechanics education. Taking a starting point in a course in Ventilation Technology, including room air flow and contaminant distribution, it explains how ICT may be used actively in the learning environment to increase efficiency in the learning process. The paper comprises past experiences and lessons learnt as well as prospect for future development in the area. A model is presented that describes a high efficiency learning environment where ICT plays an important role.*
Traditionally, education in Ventilation Technology has been a combination of teacher performance at the blackboard combined with student exercises by paper and pencils. Sometimes a visit to a building has been included to see how things look like in the real world. In order to increase learning efficiency it has been tried to make use of several tools for knowledge transfer ranging from the traditional blackboard over physical demonstrations of air flow in a full-scale laboratory mock-up to virtual reality demonstrations. Students have different ways of understanding a certain topic, using a broad range of tools for knowledge transfer facilitates deep understanding and increases learning efficiency.
Air flow is by nature invisible and represents a further challenge in the effort of providing sufficient understanding of typical flow patterns and behaviour of room air flow. An example of visualisation of room air flow by means of Computational Fluid Dynamics is presented by vector plots, flow fields and movies. It is discussed how different display systems like low-cost VR (e.g. active and passive stereo viewing) and high-cost VR (e.g. CAVE) can be applied and gained experiences are reported.
It is found that a combined application of various tools for knowledge transfer increases learning efficiency, for instance it is seen that a combination of physical experiments in laboratory and virtual experiments by computer simulation has a high level of synergy. A model for a combined use of several learning tools is presented. The model describes the teaching method and the pedagogical means. It explains how different learning domains – physical as virtual – may be combined to form a high efficiency learning environment (HELE).

KEYWORDS: *ICT supported learning, fluid mechanics, education, problem based learning, virtual reality,ventilation technology, learning efficiency*

1. INTRODUCTION

Traditionally, teaching - rather than learning - has been the issue. How does the teacher perform at the platform, do the students show up in class, will they be able to pass their exam without too high percentage of failing, will there be too many complaints, are the students satisfied with the “entertainment”, etc. Questions like that have often been more in focus than the issue of learning. Whereas teaching is more about what happens outside the student’s head, learning is engaged on what is going on inside the head, i.e. how the material, knowledge or new skills are perceived and “caught” by the student.

During the last couple of decades learning has become the hot issue in education. Much attention has been given on how to generate learning and provide deep knowledge. New ways to work have been examined both regarding the organisation of the teaching and the communication tools among other things.

Speaking of organisation classroom lectures and individual study have been supplemented by group based learning. Teamwork combined with mutual support and motivation among group members are found to support the learning process and to increase the percentage of students who pass an exam. The traditional subject bound teaching has been expanded by problem based learning (PBL). The starting point of PBL is, as the name implies, a problem - preferably from the real world. The students are motivated by the fact that they are learning to solve real issues by themselves and not just doing textbook exercises. The learning comes from the entire process of analysing the problem using some new or already learned theory and practise to, finally, solve the problem. The learning comes from undergoing the entire process and not just figuring out a suitable solution. The aim of PBL is to supply skills in problem solving and – along the way – to add new knowledge and skills to the student.

The available communication tools in education have increased substantially in number and quality during the last years. Few years ago chalk and blackboard were the major communication means apart from the teacher himself. The issue was then how to use the sparing place on the blackboard in an orderly and neat way. Today, LCD has become a de facto standard in most classrooms providing the possibility to use colour pictures, striking PowerPoint slides, all kind of movies and videos as well as low-cost VR. Apart from classroom "tools", almost all students of today have access to the Internet either from home or at least from their educational institution which enables easy communication round the clock with fellow students, group members, classes, teachers and other information resources on the Web. The Internet is not just for occasional distance learning, but has truly been a natural part of life and daily communication. For instance, instead of publishing massive amounts of paper the teacher of today puts his lecture notes, slide copies, exercises and corresponding solutions on the password protected homepage for student access. ICT, Information & Communication Technology, in education is a reality.

However, the availability of the new technologies does not necessarily mean that they give optimum learning for the students. This paper discusses some aspects of ICT-supported learning and the challenges of teaching fluid mechanics. This is followed by a suggested model for a high efficiency learning environment for teaching fluid mechanics and a description of a specific case, where the model can be implemented.

2. ICT SUPPORTED LEARNING

The use of Information and Communication Technology in university teaching has increased significantly during the last decade. ICT has given new ways of capturing, manipulating, storing, transporting and presenting information and this affects many aspects of the learning situation. Christiansson (1999) states that the most important changes are:

- higher emphasis on learning (and learning to learn) than teaching,
- the teacher becomes more of a tutor (coach, facilitator) than an information disseminator,
- higher possibilities for distant learning (not in a physical but in a virtual classroom),
- life long learning perspective becomes an important issue (time independent learning),
- new types of interactive learning material with more realistic and user adapted interfaces,
- greater possibilities to combine courses from different universities (virtual universities),
- possibilities to adapt and/or develop new pedagogical methods with respect to learning material, learning modes (exploration, discovery, problem based learning etc.), student competence and intelligence profile, collaboration, teacher roles, and social contexts,
- higher demands on client competence in connection with specification of distributed learning system and tools.

From the MERLIN project (Barajas, 2002) it is also found that ICT in learning alters traditional teacher-student relationships, and that "Change of organisation in the classroom appears to be caused by the combined effect of the media being used and the teaching approach being applied, that of placing emphasis on the learning processes rather than the outcomes, and on social learning rather than individual learning." Yu et al. (2002) describes an example of web based learning tools to facilitate individualized learning within basic fluid mechanics in pipe flow.

In addition to the traditional classroom and laboratory, it is now possible to have a number of virtual communication rooms for both asynchronous and synchronous communication in the student-student and teacher-student relationships. These communication rooms can be accessed from different locations such as the students group room, the lecture room, the teachers' office, the students' home etc. Some of these aspects are discussed by Lerche Nielsen (2002), who reports experiences with implementation of ICT in project organised studies and Fibiger (2002), who describes methods for the didactic design of virtual learning environments. Also Haynes (2002) discusses the concepts of virtual learning environments and focuses on the new roles of the teacher/lecturer and the learners and the resources needed for the change process. The impact of the new technologies on students and teachers is reviewed by Knezek et al. (2001).

The impact on learning of computer mediated communication is discussed by Hutchings (2002). She focuses on teaching methods and learning in an ICT supported environment and discusses the interaction types ‘one alone’, ‘one-to-one’, ‘one-to-many’ and ‘many-to-many’ in relation to learning modes, learning methods and learning resources. The factors that influence an effective technology-mediated teaching and learning environment are investigated by Geer et al. (2001) who have developed a model coupling learning outcomes, types of interactionand the communication technology.

3. TEACHING FLUID MECHANICS

Three-dimensional fluid flow can be difficult to visualise and understand, especially in case of ventilation and airflow due to the fact that it is by nature invisible. In most practical cases, the flow is turbulent and thus too complex to measure or simulate in full detail. It is therefore necessary to use time-averaged or volume-averaged models to describe the overall flow to a certain level of detail depending of the actual application. The models used to investigate the flow can be set up in a physical space or in a virtual space.
The major tools to investigate and visualise fluid flow are:

- Full scale laboratory experiments
- Laboratory Scale models
- Field measurements
- Computational Fluid Dynamic (computer simulation, numerical solution)

The first three are based on a physical space, while the latter is based on a virtual model space. In the following facilities to investigate and visualise indoor environmental engineering fluid flow at Aalborg University is presented:

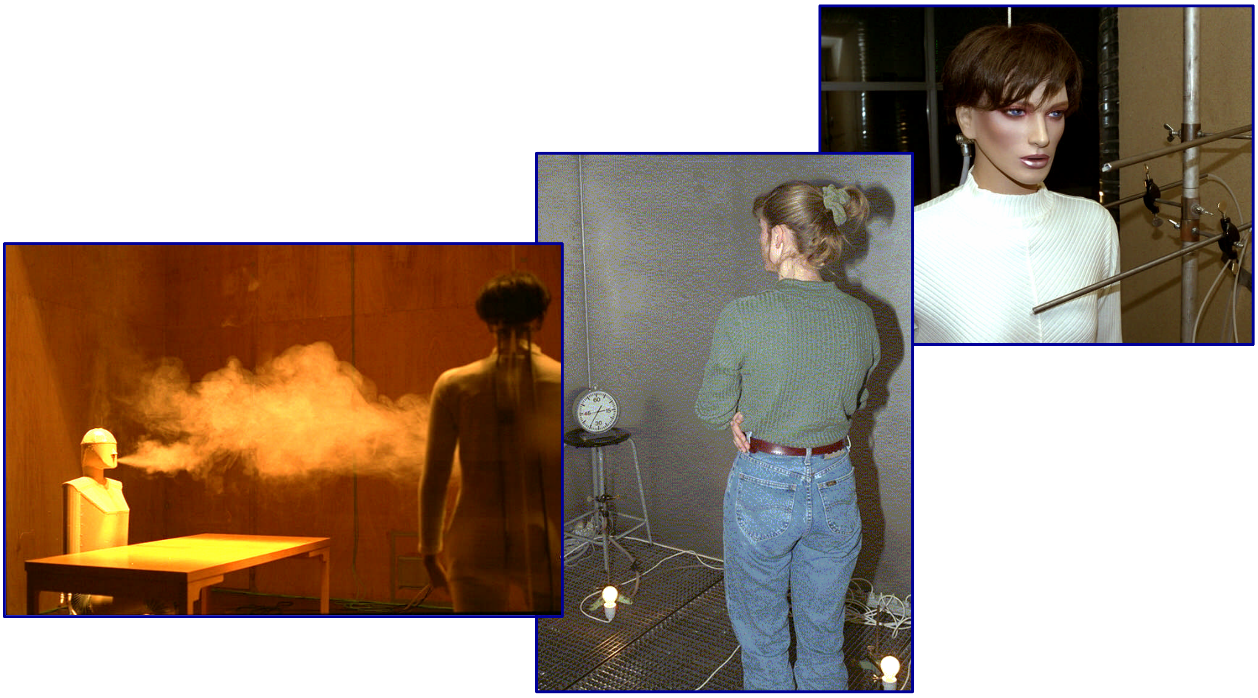
Full-scale laboratory experiments and scale models
Aalborg University has three multipurpose full-scale indoor environmental engineering laboratories as well as the possibility to build scale models to study isothermal and buoyant flow. The rooms have flexible air conditioning systems and can be equipped with a variety of measuring equipment for multipoint temperature measurements, air velocity and turbulence measurement, tracer gas measurement, laser-doppler anemometry, smoke visualisation etc. Fig. 1 shows examples from full scale measurements of airflow around persons and physical models of persons.

Field measurements
In addition to the laboratory facilities, researchers and students often bring measuring equipment to existing buildings to study the conditions in real life cases. See e.g. (Svidt et al. 1996), who studied airflow and thermal conditions in an atrium by means of smoke visualisation, tracer gas measurements, air velocity measurements and multipoint temperature measurements. Fig. 25 shows observed airflow patterns in an office building with natural ventilation. (Brohus et al. 2003) made detailed field measurements in the Bang and Olufsen headquarters, Denmark. Fig. 27 shows an example of measured concentration distribution in the office.

Computational Fluid Dynamics
Computational Fluid Dynamics (CFD) is a technique for calculating mass transfer, heat transfer, turbulence and other parameters of the fluid flow within a certain calculation domain. The aim of Computational Fluid Dynamics is to provide a numerical solution of the mathematical equations governing fluid flow and related physical processes, e.g. Navier-Stokes equations, see Fig.2. The set of equations actually involved and the appearance of the specific terms in the equations depend on the case of interest due to different assumptions and possible simplifications, e.g. thermal vs. isothermal flow and compressible vs. incompressible flow. In principle, the calculation domain is divided into a high number of small control volumes. In each control volume velocity vectors, pressure, temperature etc. are calculated. The solution is determined by the boundary conditions which include room geometry, position of fluid inlets and outlets, inlet velocity and temperature, position of heat sources and obstacles etc. Once the flow field is described in this way, it is possible to calculate scalars such as contaminant distribution in the domain when boundary conditions for the contaminant sources are known.

The principles of CFD have been used for almost four decades (Launder and Spalding, 1974); (Nielsen, 1974). Today CFD is widely used in education and industry for calculation and visualisation of fluid flow in a high number of applications. See e.g. (Svidt, 1994) and (Brohus, 1997). Fig. 3 shows examples from a study of virtual models of persons with different level of detail.

FIG. 1: Physical full scale models and real persons applied in laboratory measurements



$$\frac{\partial}{\partial t}\left(r u_i\right) + r u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j}\left(m \frac{\partial u_i}{\partial x_j}\right)$$

FIG. 2: Fluid flow is governed by the so-called Navier-Stokes equations, a set of partial differential equations.

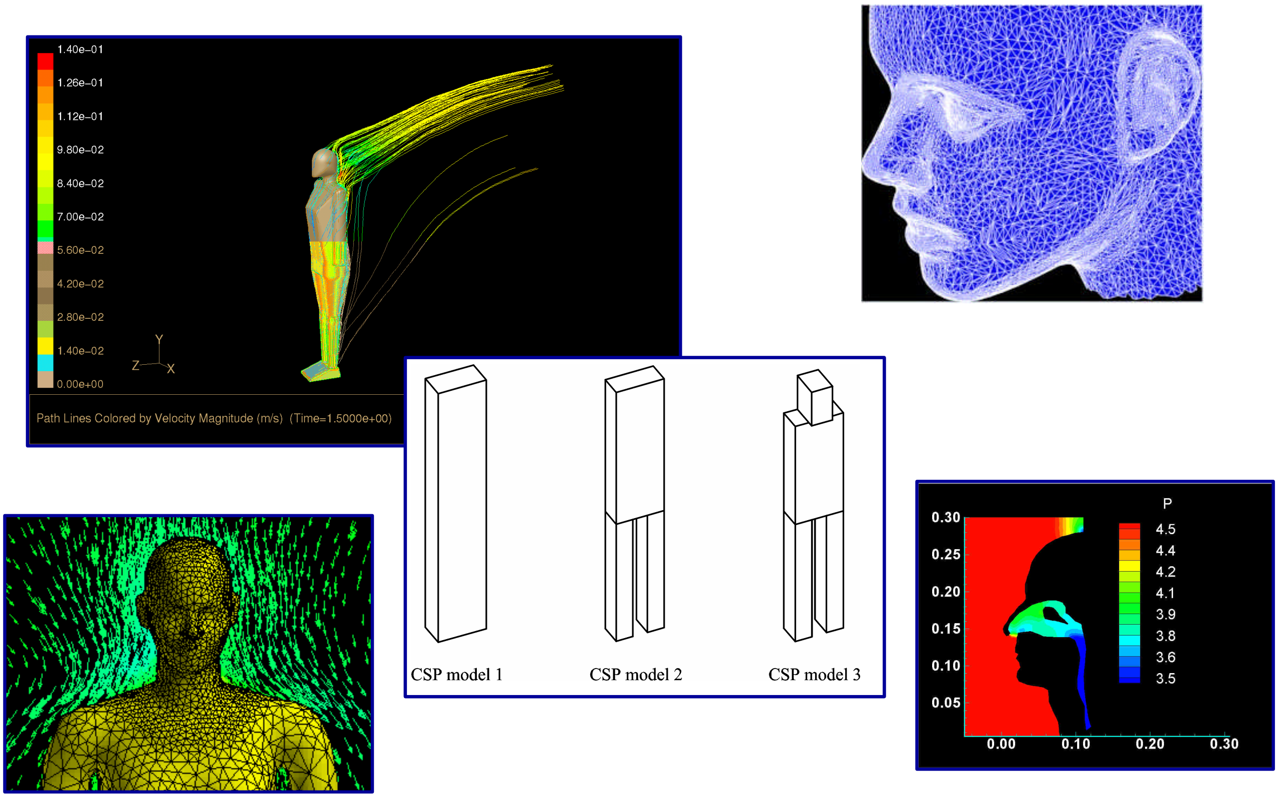


FIG. 3: Virtual models of persons, Computer Simulated Persons (CSP) with different level of detail used to study airflow around persons and personal exposure (Brohus, 1997). Click here for video animation of the lower left figure.

Animation 1 http://it.civil.auc.dk/itcon/animation1.avi (6 MB)

No matter if the investigation of fluid flow is based on a physical or a virtual model, there is a number of steps to go through and a number of decisions to make from building the model to the presentation of the results, see Table 1. In both cases we only have a limited number of discrete points where we can capture data from the continuous model domain in time and space. In the physical models, the number of sampling points is limited due to both economical and technical reasons. Each sensor is often relatively expensive depending on the type of measurement, but it is also very important to be aware that any sensor in the flow domain will normally affect the flow field, which may lead to misleading results.

TABLE 1: Capturing, storing and presenting fluid flow data, physical vs. virtual models

	Origin of data	
Action	*Physical model or field measurement*	*Virtual model*
Build the model	Define aims, scope and requested level of accuracy Set up physical model Establish boundary conditions Decide the necessary resolution of measuring points in time and space, sampling frequency, integration time etc.	Define aims, scope and requested level of accuracy Select analytical or empirical model Boundary conditions and governing equations, ordinary differential equations or partial differential equations Define geometry and grid
Generate and capture data	Add particles to the fluid (smoke, dye, bubbles) Highlight specific areas (e.g. light sheet) Photos and video capture of the above	Solve the equations (analytically, numerically) Select solution method Chose software, e.g. CFD program

	Multi point velocity and temperature measurements Thermography, surface temperature capturing Particle Image Velocimetry (PIV) Use of the human senses (*in situ*) Data logging	
Store data	Text Application specific files/databases Spreadsheet Photos and video Remember what you saw	Text 3D model including geometry and flow data Spreadsheet Computer generated graphics, pictures, video Information integrated in software applications
Present (extracts of) the data. Spatial and temporal browsing in data	2D and 3D contour planes of e.g. temperature, velocity etc. Iso surfaces Profiles and tables of e.g. velocity Vector planes, surfaces or volumes Sketches and rendering (showing flow paths) Video and stills of experiments Animations of measured data	2D and 3D contour planes of e.g. temperature, velocity etc. Iso surfaces Profiles and tables of e.g. velocity Vector planes, surfaces or volumes Streamlines Interactive models Animations, e.g. fly through videos
Select suitable display system	Show model or full-scale demonstrations on location Oral presentation Blackboard, whiteboard Printed material, posters, papers Overhead or multimedia projector PC monitor Power wall HMD (head mounted display) CAVE	Oral presentation Blackboard, whiteboard Printed material, posters, papers Overhead or multimedia projector PC monitor Power wall HMD (head mounted display) CAVE

By means of the above models and tools, it is possible to present fluid flow information at a number of different abstraction levels, see Fig. 7, starting from a simple description in words where the student would have to imagine the flow himself referring to his existing knowledge. Next level can be simple sketches and vector plots e.g. as shown in Fig. 4, which show that it is possible to give students an idea of complex three-dimensional flows by means of simple black and white drawings. However, the students still have to imagine the three-dimensional structures from the stationary two-dimensional plots. To further reduce the abstraction level, computer generated, coloured 3D plots, animations and video clips can be used, which may be considered typical visualisation tools of today. The illustrations in Fig. 3 comprise three dimensional models, which can be shown as video animations or rotated by real time user interaction, which significantly improves the understanding of the three-dimensional flow. Fig. 5 shows an example with a combination of drawing, photo and video to explain cold airflow from a window. To further improve the understanding of the 3-dimensional aspects of the flow, one step further down in the level of abstraction may be taken by using a number of the elements of Virtual Reality (VR), which will be described below.

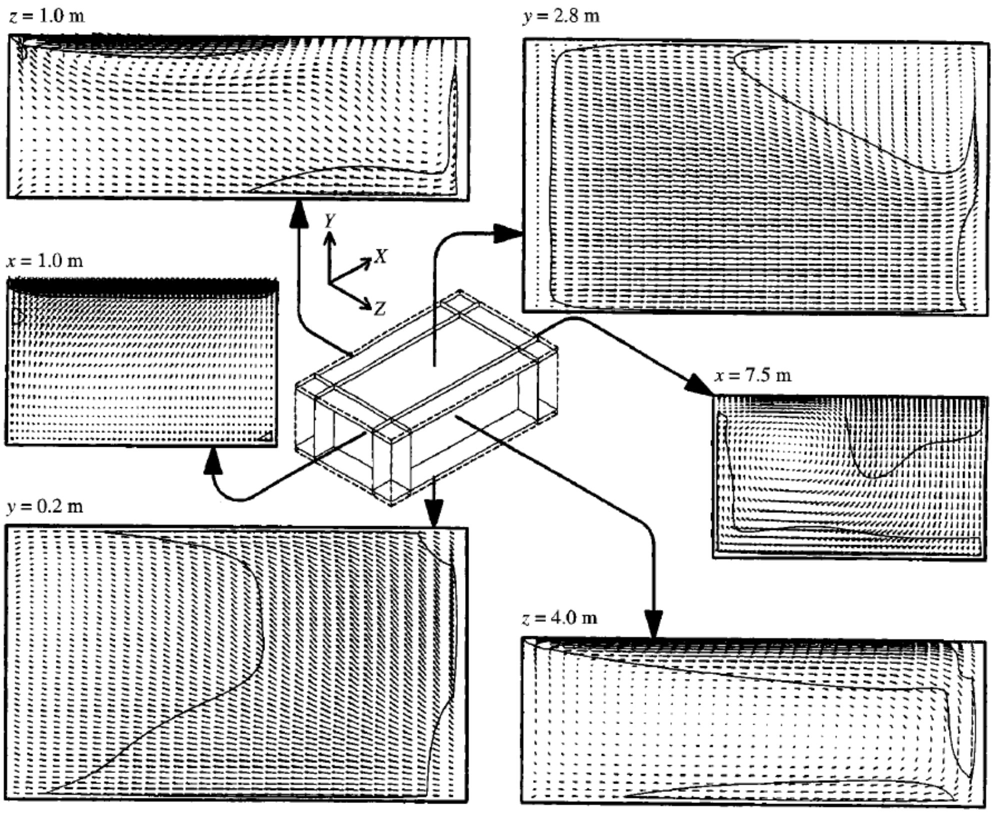


FIG. 4: Three-dimensional airflow simulation results illustrated by a number of two-dimensional plots (Bjerg et al., 1999)

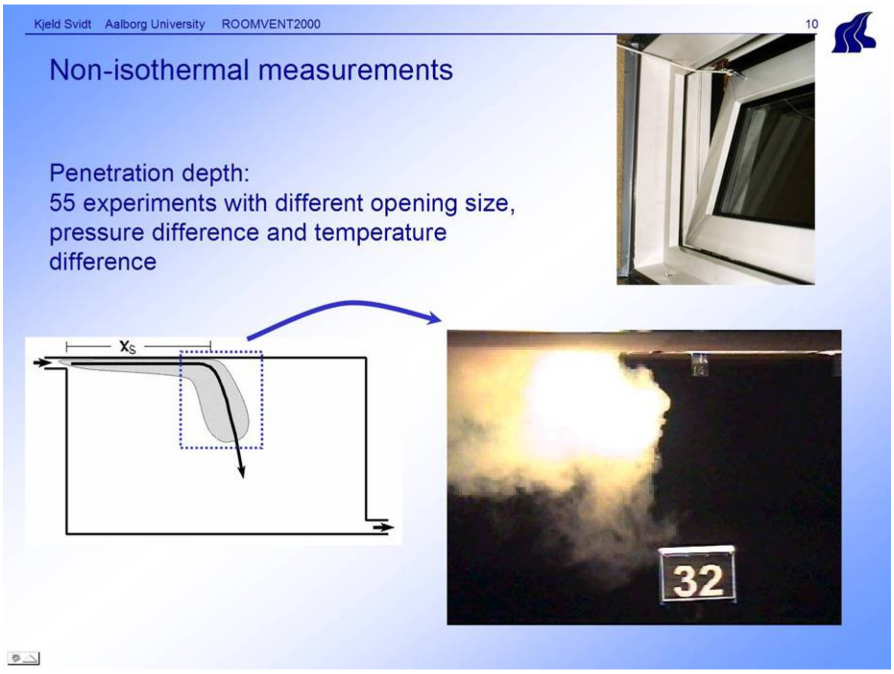


FIG. 5: A combination of drawing, photo and video to explain cold airflow from a window. Download video clip of smoke visualisation as Animation 2 (Svidt et al., 2000)

Animation 2 http://it.civil.auc.dk/itcon/animation2.avi (5 MB)

3.1 Virtual Reality visualisation of fluid flow

The term "Virtual Reality" (VR) was initially introduced by Jaron Lanier in 1989 (Schroeder 1993), while the ideas of such a display system originate from Ivan Sutherland (Sutherland, 1965). Today, there exist many different views of its meaning depending on which context it is used in. In this work Virtual Reality is defined as an environment trying to convince your senses that something virtual is real. It will normally include some of the following elements:

1. Real-time interaction with the model
    - mouse or keyboard
    - tracking of persons
    - tracking of interaction devices
    - haptic devices (touch feedback)
2. Stereo viewing, i.e. different pictures for right and left eye
    - active (shutter glasses)
    - passive (colour or polarisation filter)
3. A certain degree of immersion
    - wide screens, power walls
    - large curved screens
    - CAVE (Cave for Automated Virtual Environment)
    - HMD (head mounted display)

For more information on Virtual Reality, see. e.g. (Vince, 2004); (Stuart, 2001); (Giallorenzo et al., 1999); (Christiansson et al., 2001).

3.2 Virtual Reality facilities at Aalborg University

The VR Media Lab at Aalborg University was established in 1999 with three different display systems. The display systems are:

1. A 6-sided CAVE (Cave for Automated Virtual Environment) which is a cube (2.5 m x 2.5 m x 2.5 m) with real-time image projection on all six sides. By means of an electromagnetic tracking system the viewer can move in (or around) the visualized object. This installation is preferably for one viewer (Fig. 6).
2. A Panorama, which accommodates up to 28 persons placed in front of a large 160 degrees cylindrical screen with a diameter of 7.1 meters and a height of 3.5 meters, thus the major part of the viewers field of vision is covered (Fig. 6). (Active stereo viewing)
3. A 3D Auditorium accommodates up to 80 persons placed traditionally in front of a large screen (power wall) measuring 8 x 2.85 meters (in this context we define "power wall" as a large flat screen that can show stereo images with possibilities for real-time interaction). (Passive stereo viewing)

All three arenas have electromagnetic tracking of interaction devices, so the presenter can interact directly with the model in front of the audience.

Fluid flow has been visualised in the VR Media Lab based on simulations using the commercial CFD-code Fluent, see Bjerg et al. (1999) and Svidt et al. (2001). The stored results are displayed with the visualisation code VU (www.cerca.umontreal.ca/vu). VU is a program, where the presenter can interactively move and scale the model and in real-time navigate in the three-dimensional data set. The data are visualised as filled contour planes or vector planes which the presenting person can move around arbitrarily in the model. In addition the presenter can place or interactively move around seed points for streamline visualisation or moving particles in an intuitive way by moving physically around in the model.

In the cases where Virtual Reality is used, a high degree of immersion, stereo viewing and tracking of persons and interaction devices are the VR elements that differentiate this visualisation from a more "traditional" 3D-visualisation. The VR facilities have proved to be very efficient to visualise three-dimensional fluid flow for people with no special background in 3D modelling and fluid motion, however, it is important to notice that these VR facilities are very expensive. Considering cost versus learning efficiency, it is important to look also at recent developments in low cost VR solutions which make it possible to display interactive 3D models on an ordinary wall by means of colour coded images and inexpensive colour filter glasses, see Fig. 6.

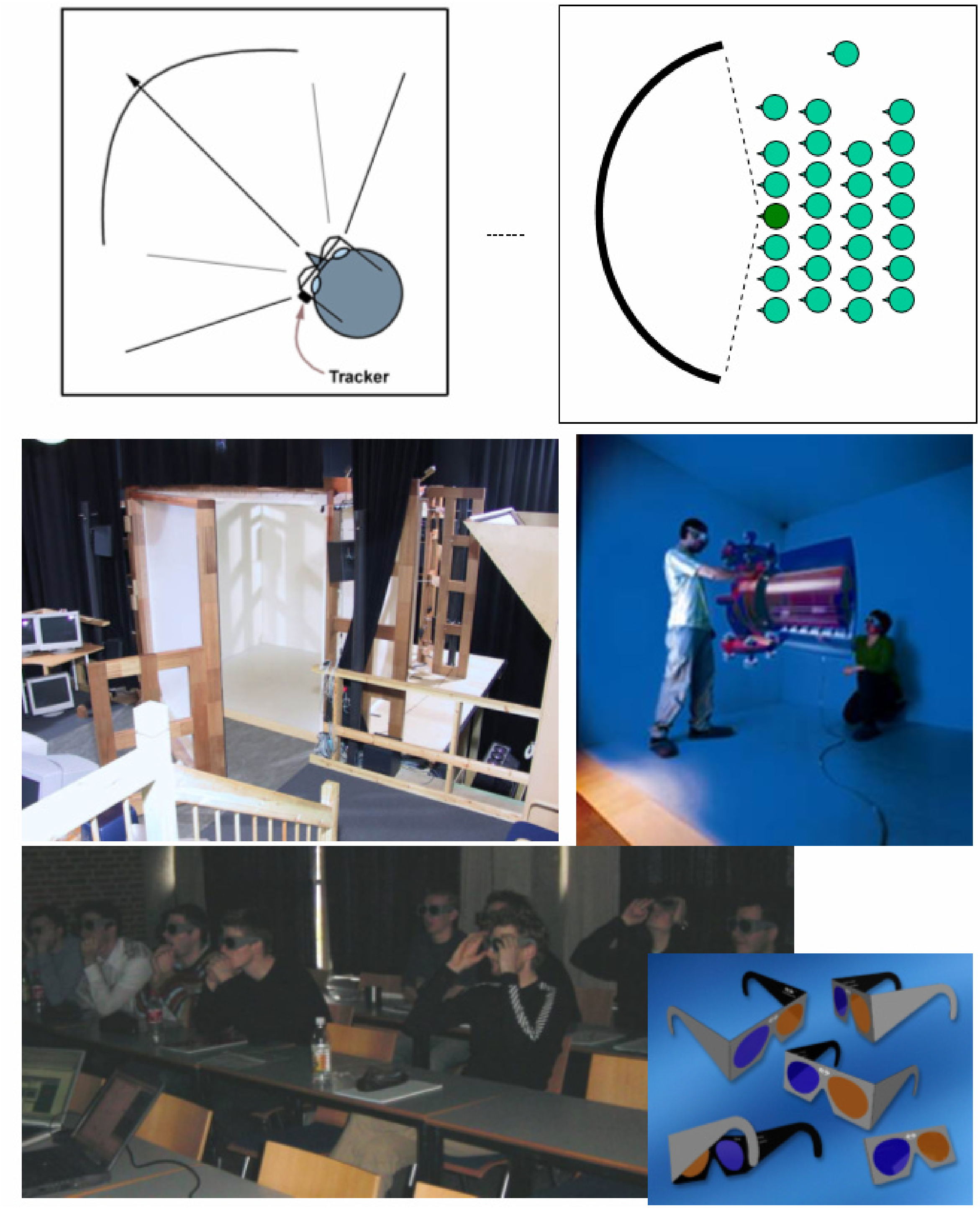


FIG. 6: VR tools at Aalborg University, Denmark.
Top: The panorama with a large cylindrical screen accommodates up to 28 persons.
Centre: The 6-sided CAVE (Cave for Automated Virtual Environment) has back projection on all sides and position tracking of the main viewer. Left: Entrance to the CAVE at Aalborg University. Right: Visualisation of 3D objects inside the CAVE. Bottom: Students wearing low cost stereo glasses to see 3D stereo models in a classroom with a conventional screen and projector.

4. THE HELE MODEL (High Efficiency Learning Environment)

The experiences from teaching a number of courses with different elements of fluid mechanics theory and practice, and a wide use of more or less ICT-dependant demonstrations and visualisations of three-dimensional flow principles has led to the formulation of the so called HELE model. HELE is an abbreviation of High Efficiency Learning Environment. The overall idea of the model is to generate or create a motivating environment that facilitates deep learning in an efficient way. In this context "environment" should be understood quite broadly as will appear clearly from what follows. The HELE model, rather than inventing a specific tool or distinct pedagogic variety that "does the job", focuses on applying "old" tools - including cutting edge ICT - in a new and reorganised way. To mention one of the significant differences compared with traditional education, the teacher does not merely teach but instead s/he acts as a supervisor responsible for guiding the students in the learning process in the framework of several learning environments.

ICT plays a major role in the HELE environment, however, ICT is not the goal but a means to an end. The model acts as a guideline for the application of ICT. In that way it is ensured that ICT is applied whenever appropriate to enhance the quality of teaching, neither more nor less, see Fig. 7.

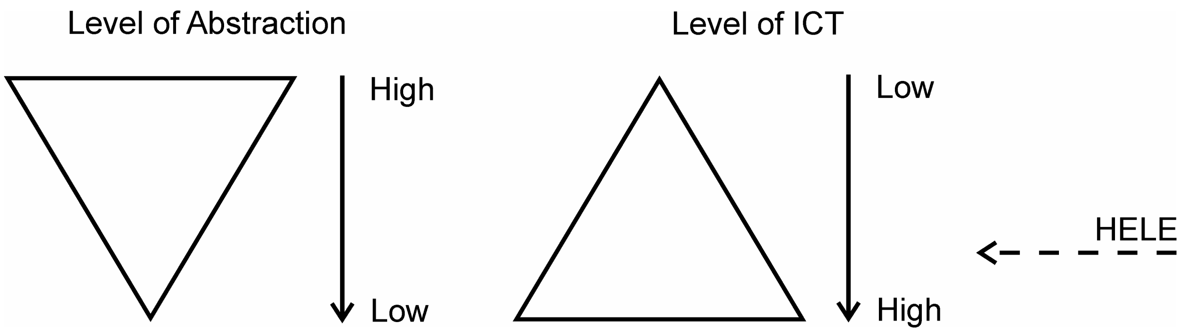


FIG. 7: To facilitate learning HELE utilises a relatively high level of ICT to ensure that the required level of abstraction be kept at a reasonably low level. The purpose is twofold; to make sure that a rather large proportion of the students obtains deep learning, and to optimize students' learning curve. ICT combined with deliberate organisation of learning means and learning environments are supposed to boost learning efficiency in general.

It is believed that a reduction of the level of abstraction in education will increase the learning efficiency significantly. "The less able students, the more ICT needed" or to put it in a more progressive way "the more ITC, the more students reached". However, it need not be a question only of "the more, the merrier", i.e. solely quantity, rather it is a question of both quantity and quality.

As an example imagine that a certain complex flow field is described solely in terms of governing equations and extensive boundary conditions compared with a laboratory demonstration or video showing the same flow field. In this case it is obvious that the level of abstraction differs remarkably. The visualised flow may be understood (at least for an overall first understanding) almost without any previous training, whereas the "raw" equations in itself requires quite an able student to grasp the picture. In order to decimate the comprehensibility gap that prevents many students from the experience of deep learning, ICT may be an effective tool. The HELE model sets up a framework for the application.

The following paragraph takes a starting point in the traditional way of teaching and explains how teaching is performed in the framework of HELE ending with a definition of the entire model.

Often the traditional role of a teacher has been a blackboard-bound speaker upholding high authority pouring out grains of wisdom – pushing it to extremes. Most often than not the communication has been one-way (from the teacher to the students), see Fig. 8 and Fig. 9. The mutual relationship and the authority of the teacher are based primarily on position.

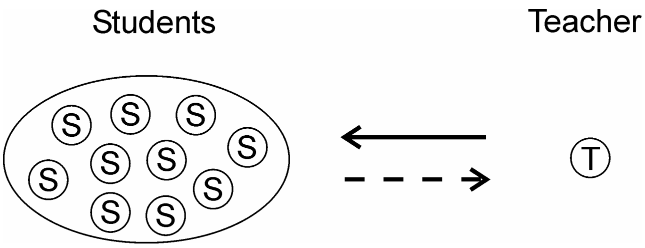


FIG. 8: Traditional one-way teaching from teacher's desk. S = Student, T = Teacher.

The HELE "supervisor" role aims for two-way communication whenever suitable. Sometimes it is most efficient to give "concentrated" lectures with limited possibility for dialogue apart from few questions and some discussions, however, a significant part of the time ought to be allocated for dialogue for instance during exercises, group work supervision, personal communication, etc. To facilitate this two-way communication the authority of the teacher/supervisor must not be tied to the position only, but instead include high level of technical and personal authority.

Another question is "who is the central figure" of the learning process? The traditional way of doing things may be symbolised by the bottom left illustration in Fig. 9. The teacher is in centre.

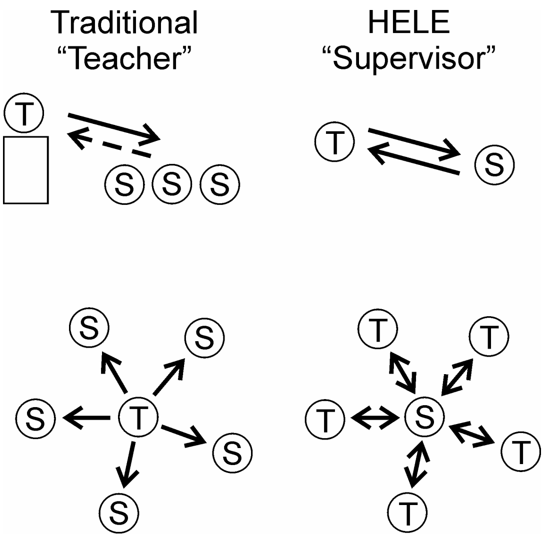


FIG. 9: Teacher's role in learning. Traditional "teacher" role (left) versus HELE "supervisor" role (right).

In HELE the traditional teacher is replaced by a supervisor. It is still an important part of the work to "teach" but the way is somewhat different than the usual role of a teacher. The supervisor acts more like a "conductor" orchestrating the learning process, see Fig. 10. To obtain an efficient learning curve, the supervisor must choose the right tool or method for the right purpose at the right time, and the students must have some time for reflection to process the information between the teaching events. Sometimes the supervisor will be present (physical or virtual) and lecture or guide/supervise the students. However, part of the process may be to arrange for a guest lecture, a visit in the laboratory, a field trip, hand out assignments and make the students do some homework, initiate group work (Fig. 11) or self-tuition, etc.

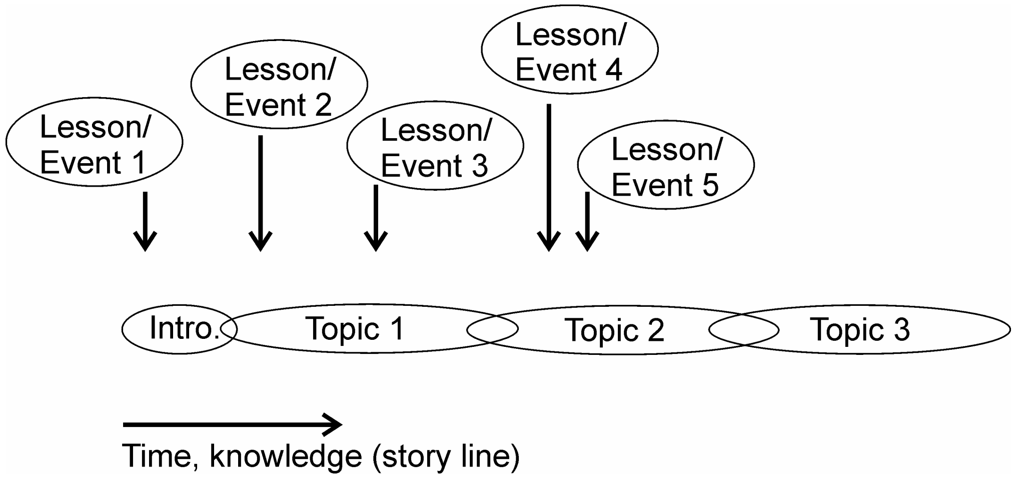


FIG. 10: Progression of learning in HELE. The main principle may in brief be described by: "Just in time – just enough". The learning situation is at the same time a filtering process that includes time for reflection. The supervisor orchestrates the learning process.

In that way the principal role of the supervisor is to keep track of the students' learning process - ensuring efficient learning and proper skill development - rather than "shouting oneself hoarse" from the blackboard. Part of this may obviously include traditional lectures, but not necessarily the vast majority of the time.

Testing and exams are obviously part of the supervision to assess the learning progression and final result. Active application of ICT, e.g. in shape of online questionnaires, online tests, interactive assessment of academic level, etc. may facilitate frequent examination in a relaxed environment (online). This constitutes a very useful tool to tailor each course according to the specific needs of each student – depending on the resources available – and obviously also the entire student mass. In that way, the learning process can be monitored along the way and useful insight can be accumulated to initiate immediate action as well as for future improvement. The composition of the tests and online assessment tools is a complex field that is outside the scope of this paper.

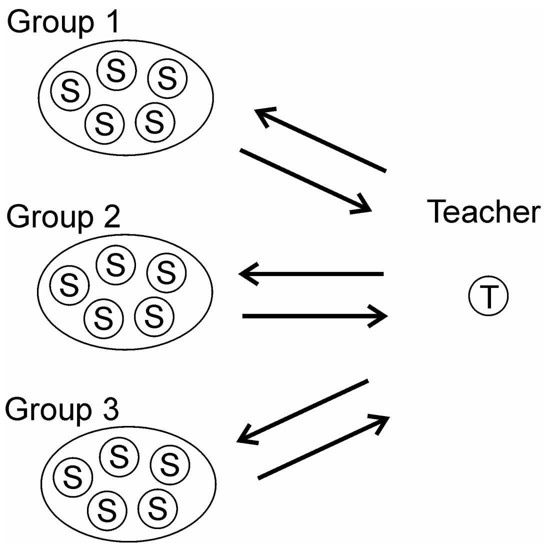


FIG. 11: Group based two-way teaching.

The role of ICT in the process is to provide a set of means to generate creative learning environments.

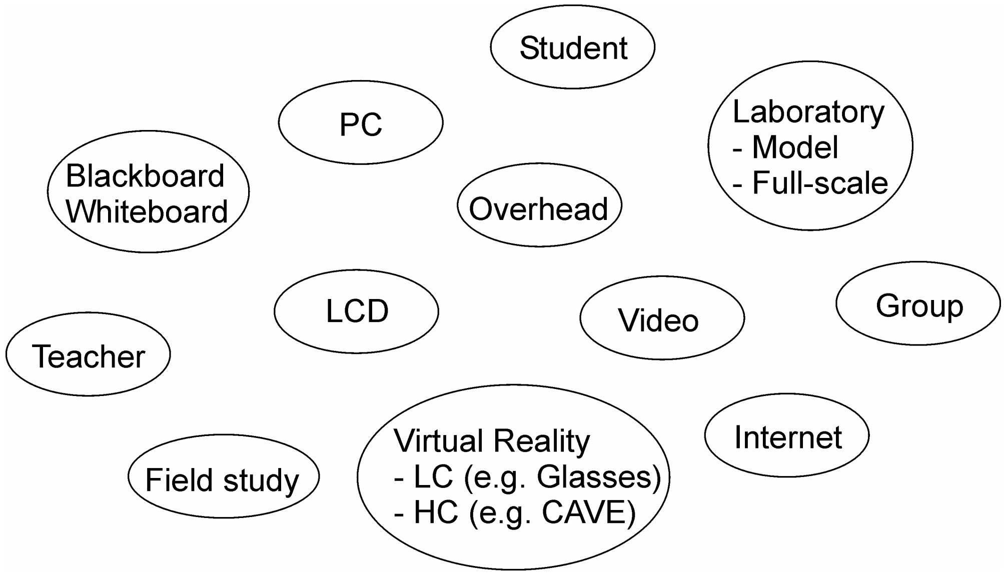


FIG. 12: Communication tools and communication environments.

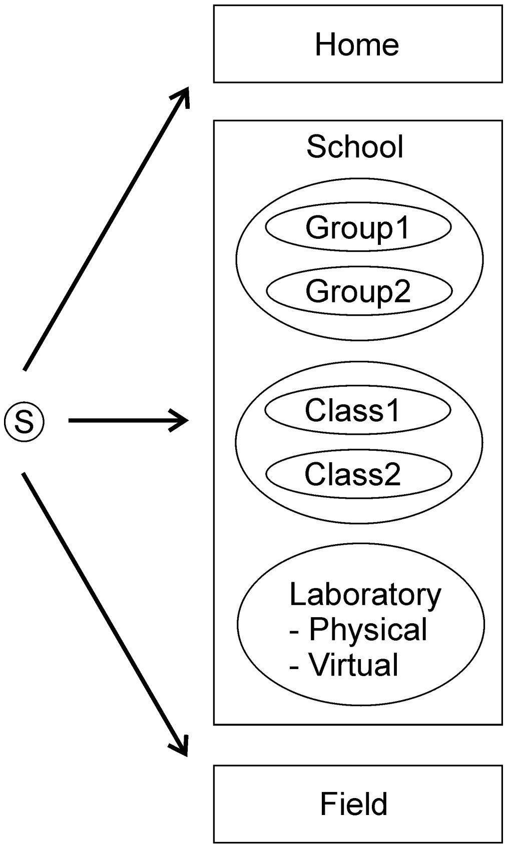


FIG. 13: Student's physical learning environments.

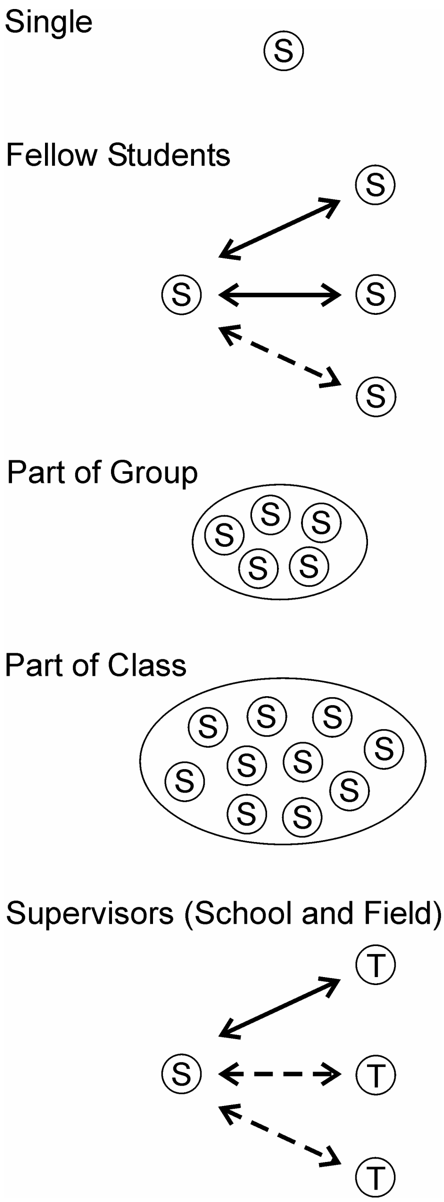


FIG. 14: Organisational environments. Student's contacts during the learning process.

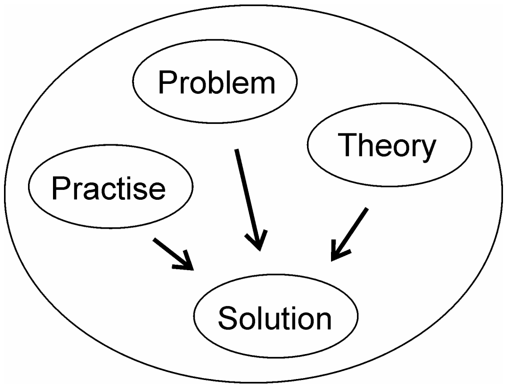


FIG. 15: Problem Based Learning (PBL), an efficient means to ensure socially relevant curriculum, to keep the level of abstraction at a reasonable level and to keep student's attention focused.

Problem Based Learning (PBL) is a central part of the HELE model, see Fig. 15. PBL takes a starting point in a - preferably - real life problem. The aim of the learning is to find one or more theoretical answers that can explain and/or solve the problem. The theoretical answer is tested e.g. empirically to examine if the theory-based answer is a valid answer or solution to the problem. Finally, a conclusion is drawn (Qvist, 2003). The definition of the problem in PBL is an important part that ought to be the student's responsibility, even though a framework may be set up by the supervisor. The supervisor is responsible for the final choice of a reasonable problem selection and for criticism and guidance during the solution process.

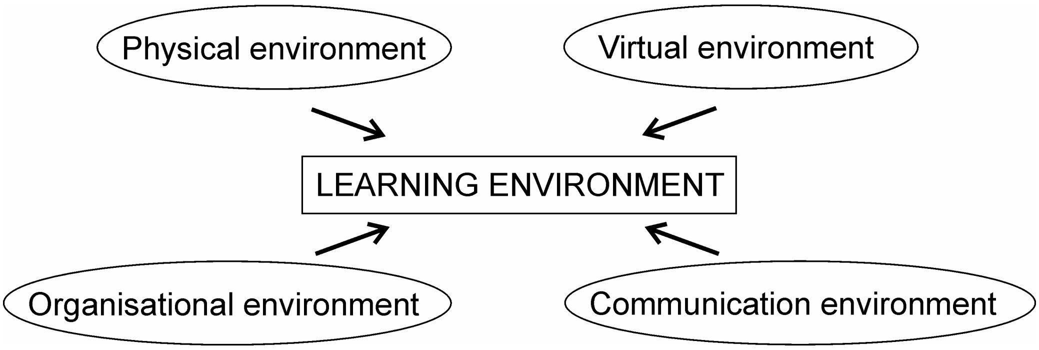


FIG. 16: The HELE model (High Efficiency Learning Environment). The model may be thought of as a meta-environment comprising dynamic change of physical, virtual, organisational and communication environments. ICT plays a significant role in the model.

The "environment" of the HELE model may be considered as a kind of meta-environment comprising dynamic change of, see Fig 16:

- Physical environment
- Virtual environment
- Organisational environment
- Communication environment

The model focuses on efficient transfer and generation of deep knowledge as well as development of new skills.

The teacher does not act in his traditional role as a desk bound lecturer. Instead, the teacher has the role of a supervisor who orchestrates and facilitates the learning process in an efficient way. The aim is deep learning rather than mere entertainment. The teacher supports the students in group oriented PBL supplemented with home study, classroom lectures, laboratory and field studies when appropriate. The teacher helps the student in goal setting and supports the learning process rather than giving it to him on a plate.

The HELE model is characterised by dynamic purpose provided change of environment. The change may be related to for instance the physical learning environment, the communication environment, see Fig. 12, (choice of appropriate communication tool) and change of "reality level". The key word is the dynamic change between different means (environments) to the end (learning).

The idea is not to find one optimum solution of the "learning problem" but to change between different means to obtain the end. The means may be the physical environment. Sometimes the lesson may be learnt most efficiently when the student sits at home highly concentrated, some other time it is more efficient to work in a group or to be taught in a classroom. These changes comprise both the physical environment and the organisational environment, e.g. single or part of a group, see Fig. 13 and Fig. 14.

The virtual environment may comprise changing from an animation showing the entire flow field to give an overview, followed by a series of vertical and horizontal fixed planes of vector plot giving a more detailed picture of the local flow field, concluding by a comparison between selected local profiles and results from literature or an analytical solution. The quality of the animation may be enhanced by VR, stereo viewing or a visit in the CAVE, see Fig. 6, if time and resources allow.

Regarding the balance between the physical and virtual environment it is thought that a change may allow for more approaches to the same subject. This will form an advanced way of repeating the points of the subject, which is a well-known pedagogical means. Instead of repeating the same words or the same figures, the issue will be highlighted by the dynamic change of “environment”. This way of working reduces the overall level of abstraction, see Fig. 7, and all other things being equal; the teaching becomes more interesting and increases the capability of catching the full attention of the students.

Using a wide range of communication means comprises the Communication Environment. For instance it could be a face-to-face discussion student vs. teacher or teacher vs. class, a printed document, a file sent by e-mail, a website, videoconferences, etc. In this way distant learning becomes a natural part of HELE, however, preferably combined with personal communication and contact to stimulate communication.

The following paragraph illustrates the idea of HELE by an example in shape of a commonly applied ventilation principle that may not be easily understood by the first grasp, namely displacement ventilation.

5. DISPLACEMENT VENTILATION CASE

In order to explain the idea of HELE a so-called displacement ventilation system is used as an application as part of a lecture in a course in ventilation technology. Displacement ventilation is a commonly applied ventilation principle that some students find difficult to understand before they have seen it working in real life, e.g. by means of smoke visualisation or a movie showing the development of flow field obtained from a CFD simulation.

The case comprises:

- Explanation of the ventilation principle in words and sketch
- Flow visualisation (vector plots, contour plots, movie, etc.)
- Application in practise (drawings, photos)
- Field study (physical case, photos of real life application – symbolising visit/excursion)

In a learning situation the engineering students will obviously also work a lot with the governing equation, e.g. the Navier-Stokes equation as described previously, and equations and theory relating to design methods. This is omitted from this case to make it clearer and less verbose, even though it is crucial to learn and to be able to use the theory. However, a few words will be said about the subject in this paragraph. To facilitate the student’s understanding of the theory and - equally important - to motivate, the ventilation principle is introduced in word and sketch, visualised, and explained in a practical setting before presenting the equations and design methods. Apart from motivation it generates an “engineering understanding” of the physical world that is necessary in order to conceive the simplifications and delimitations that is an inherent part of the engineering profession. The task is bottom-line how to model a complex world in terms of relative simple and robust design methods. A substantial part of this training is to know the assumptions made and the inherent limitations of the models. To further facilitate this part of the learning process; even the equations may be “illustrated” to enhance understanding (which may turn out to be especially beneficial for the visually oriented students). For instance the buoyancy terms in the Navier-Stokes flow equations may be symbolised by an ascending hot air balloon or smoke visualised cold downdraft along a window. This demystifies the complex learning situation and instead of alienation it provides useful links from each term in lengthy equations to a symbol and well known phenomenon from everyday life. All it takes may be a few photos and a couple of words.

In the following some of the important characteristics of displacement ventilation will be mentioned and discussed in order to give an overview of the ventilation principle.

Displacement ventilation has been used in buildings to extract excess heat and contaminants since the antique and the middle age. From the 1950s displacement ventilation experienced a renaissance in industrial applications, and from the 1980s the principle became popular in comfort ventilation, especially in the Scandinavian countries.

The reason for the growing interest in the displacement principle is a possibility of obtaining a relatively high ventilation effectiveness (roughly speaking, higher indoor air quality for less money) and temperature effectiveness (roughly speaking, better comfort for less energy consumption), and thus the possibility both to supply fresh air to the occupants and to remove contaminants and excess heat in an energy efficient and cost effective way. However, there are some limitations that should be acknowledged in order to perform a proper choice of ventilation principle and a successful design of the system.

5.1 Thermally controlled ventilation

Using displacement ventilation subcooled air is supplied in the lower part of the occupied zone of the ventilated room. The air is supplied with a low momentum (velocity) and a low turbulence level. Due to the gravity force affecting the dense air it spreads out radially along the entire floor in an almost horizontal layer with only very limited entrainment of the surrounding room air.

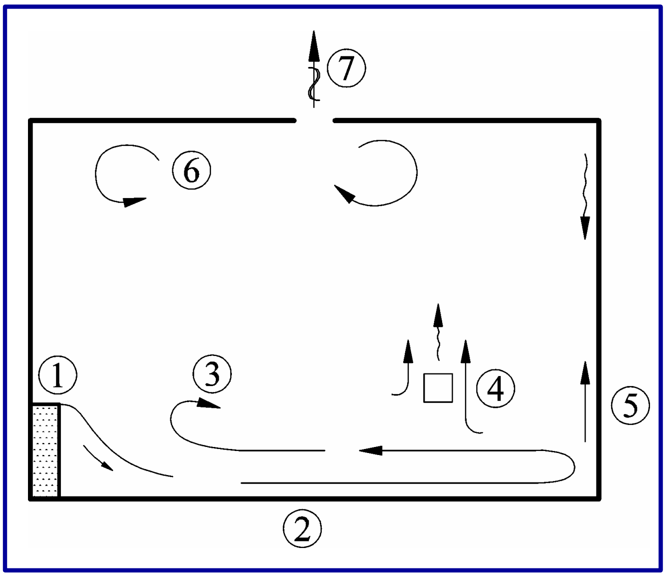


FIG. 17: Air distribution in a typical displacement ventilated room. The subcooled air is supplied in the occupied zone (1), it spreads radially along the floor (2), it is reflected at the walls (3), and part of the current is entrained into heat sources (4) and warm walls (5). In the upper part of the room a recirculation zone is generated (6), and the air is extracted through exhaust openings located close to the ceiling (7). ICT has been applied to supplement this principle sketch by visualisation of vector plots for several supply air temperatures, see Fig. 22.

In that way a stratified flow is obtained that is almost unidirectional in the lower part of the room. This kind of flow is thermally controlled and it is mainly governed by the buoyancy forces in the fluid.

The heat from the internal heat sources raises to the ceiling which in this way is heated together with the upper part of the room. Part of this heat is redistributed to the floor and the lower part of the room by means of radiative heat transfer. It results in a temperature distribution with a significant vertical gradient. This temperature gradient facilitates removal of exhaust air at ceiling level several degrees above the temperature in the occupied zone. This allows an efficient use of energy, but it may also give rise to thermal discomfort if the temperature differences are too large.

5.2 Stratification

The flow is unidirectional until the height where the net air flow rate of plumes generated by the heat sources equals the supply air flow rate. Above this height, i.e. the stratification height yst, a recirculation zone is generated.

If the contaminant sources also are heat sources the displacement ventilation system can have a high ventilation effectiveness. In this case the stratified flow implies that the room is separated in a lower, cleaner part and an upper, more contaminated part. The two zones are separated at the stratification height, yst, see Fig. 18.

The concentration distribution is one of the important differences between displacement ventilation and conventional mixing ventilation regarding the air quality. In displacement ventilated rooms the air quality in the occupied zone is comparable with the supply air quality, while in traditional mixing ventilation it is comparable with the exhaust air quality.

The stratification of the flow is quite stable, even if people are moving around in a displacement ventilated room. Especially the thermal stratification is stable (also in case of relatively violent movements in the ventilated room), while the concentration distribution is slightly more affected, but even if the room air is temporarily mixed, the stratification is quickly re-established (Brohus and Nielsen, 1996).

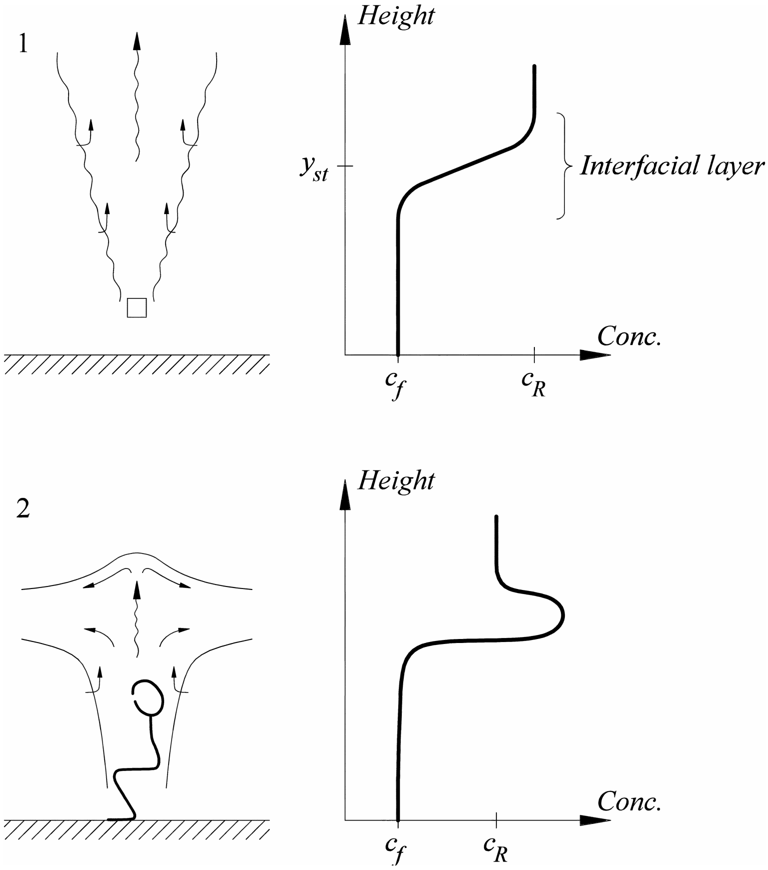


FIG. 18: Concentration distribution in a displacement ventilated room. Typical distribution where the contaminant source also is the warmest convective current (1), and where it is not the warmest convective current (2). The concentration level in the lower part of the room close to the floor, cf, depends on cold downdraught, disturbances in the room, etc. yst is the stratification height and cR is the return air concentration (Brohus, 1997)

5.3 Limitations

The supply air must be colder than the room air, therefore, there should always be some excess heat to be removed, at least for the major part of the year. If there is a temporary heating demand it can be handled by a radiator installation in the ventilated room, etc.

The contaminant sources should also be heat sources or lighter than the ambient air to obtain the concentration stratification. At the same time the exhaust opening must be located close to the ceiling.

In order to avoid thermal discomfort it is important to be aware of the adjacent zone close to the inlet device where the velocity is high and the temperature is low, as well as the vertical room air temperature gradient.

5.4 Application in practise

After the ventilation principle is introduced it is found useful to give examples of the practical application of displacement ventilation, see Fig. 19. If the student has severe difficulties imagining how this “strange thing” is to be used in real life it may be a blockage for efficient learning. The aim is to provide an understanding of how this could be (and has been) applied and - even better - the student will recognise some of the applications from her own life. This creates a useful link from familiar knowledge to new knowledge. If possible the application should range from a building in the neighbourhood that could be visited or easily contemplated to a collection of interesting famous national or international buildings by well known architects.

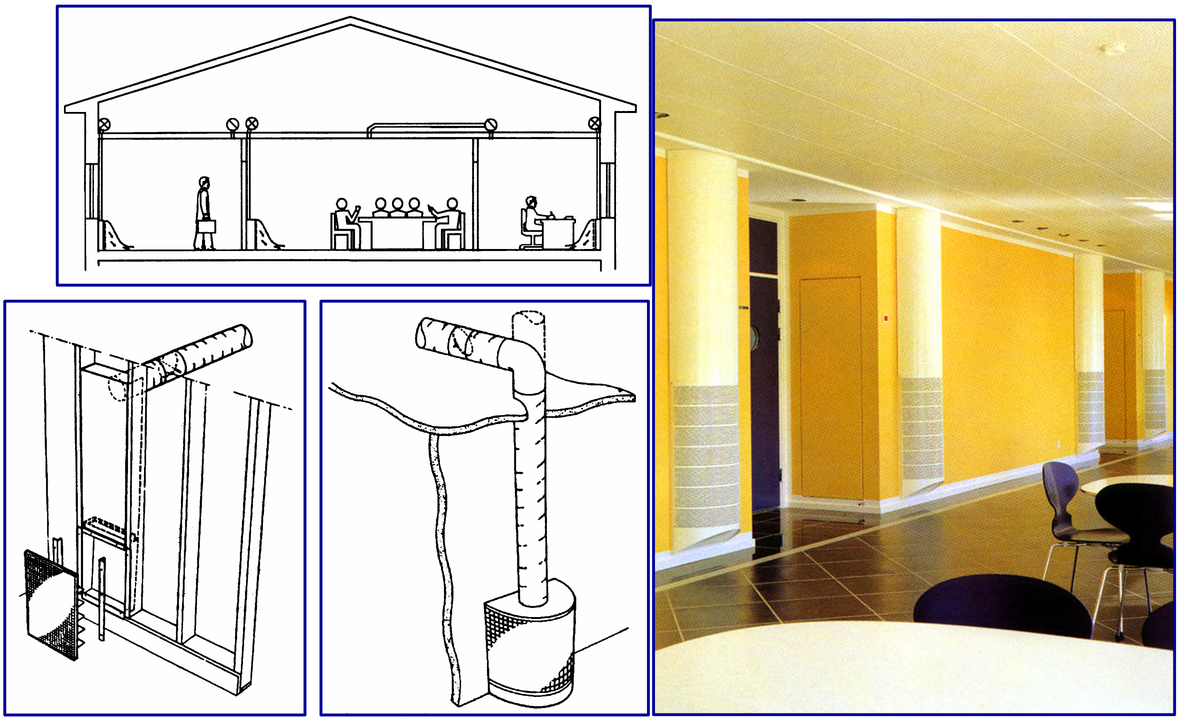


FIG. 19: Application of displacement ventilation system. Left: Sketch of a solution including occupants. Below is shown details indicating how the inlet devices can be build in. Right: Photo of application in real life. Courtesy of Lindab A/S Denmark.

5.5 CFD test case

After a more general introduction to the subject it is time to turn to a specific example or test case. Preferably this test case should comprise both a numerical part (e.g. CFD simulation) and a physical part (e.g. laboratory mock-up). Practical and economical limitations may obviously reduce the case to simulations which in that case could be made as a simple setup to avoid distracting details. This paragraph presents a numerical test case comprising a displacement ventilated room with several heat sources and a Computer Simulated Person (CSP).

Fig. 20 shows the geometry of the test case (left) and an outline of the case in the computational tool (right). Assuming symmetric flow only one symmetry plane has been simulated to save CPU time. The commercial CFD software FLOVENT has been used for the simulations. Fig. 21 show the computational grid. The solutions domain is divided in thousands of control volumes over which the governing conservation equations are solved numerically, see Brohus (1997).

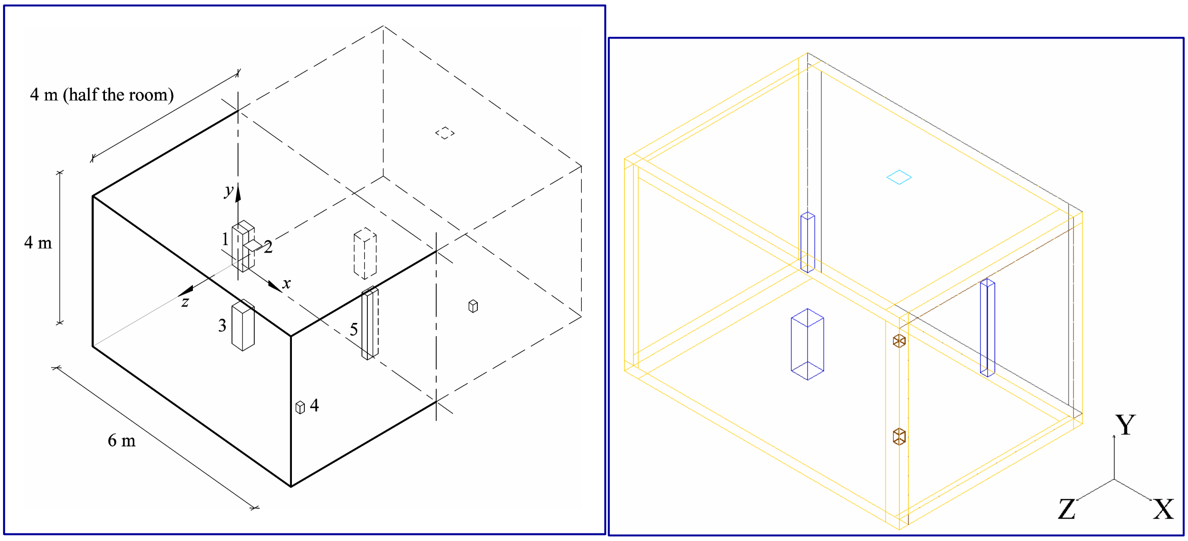


FIG. 20: Left: Geometry of displacement ventilation CFD test case. The subcooled air is supplied by a low-velocity inlet device (1) and it is exhausted through two return openings in the ceiling (2). The heat load is generated by two person simulators (3), a point heat source (4) and a Computer Simulated Person (CSP) (5), represented by a heated cuboid. Right: Outline of case in computational tool.

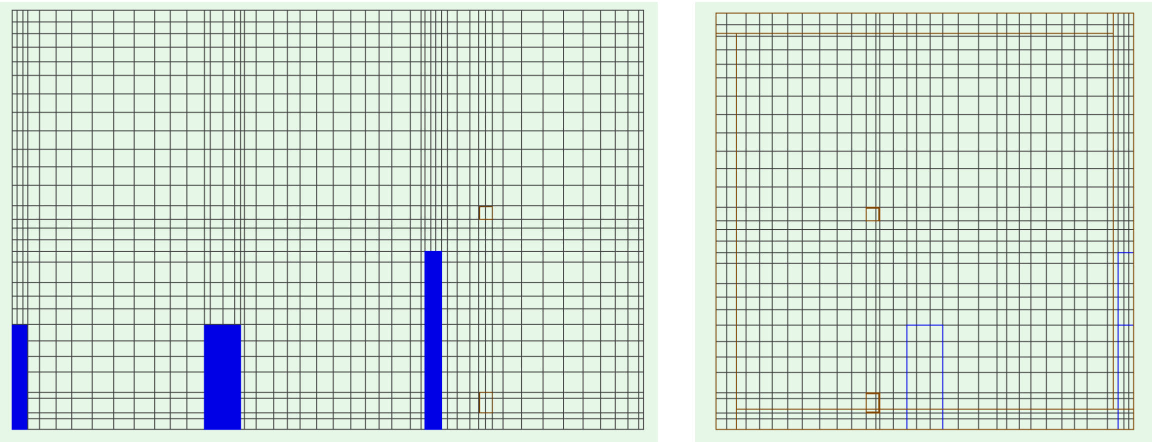


FIG. 21: Computational grid applied in the CFD simulations. Left: xy-plane, right: zy-plane

Fig. 22 gives an example of typical results in this case vector plots from the symmetry plane of the displacement ventilated room. The results clearly visualises the flow field from of the inlet device. In displacement ventilation it is crucially important that the supply air is colder than the room air to create a stratified flow covering the entire room and "purging" the room from below. If the supply air is warmer than the room air an ascending air current will be created that will short-circuit the system (fresh supply will continue directly to the exhaust opening without doing any good in the occupied zone). In this figure this principle and important design rule is visualised in a simple and efficient way. This is a typical example of an application of ICT to support the learning – in this situation this may be considered a further development of the more abstract description of the flow in relation to Fig. 17.

An advantage of displacement ventilation compared with traditional mixing ventilation is the possibility to obtain an efficient ventilation system both in terms of indoor air quality and energy consumption in case of warm contaminant sources. Regarding indoor air quality the stratified flow creates a relatively clean zone close to the floor. Occupants will entrain air in the convective boundary layer along the body and reduce personal exposure to the present contaminant sources. They are roughly speaking their own fresh air pumps. This can be seen if the flow along the Computer Simulated Person (CSP) in Fig. 22 is observed. Fig. 23 visualises the temperature and the concentration distribution of the displacement ventilated room. This visualisation also illustrates the point regarding entrainment and transport of clean air along the CSP giving rise to high ventilation effectiveness (ability to remove contaminants). The temperature distribution in Fig. 23 shows the significant stratification of the flow field with increased temperature as a function of height. This enables high temperature effectiveness (ability to remove heat) leading to reduced energy consumption and eventually lower environmental impact.

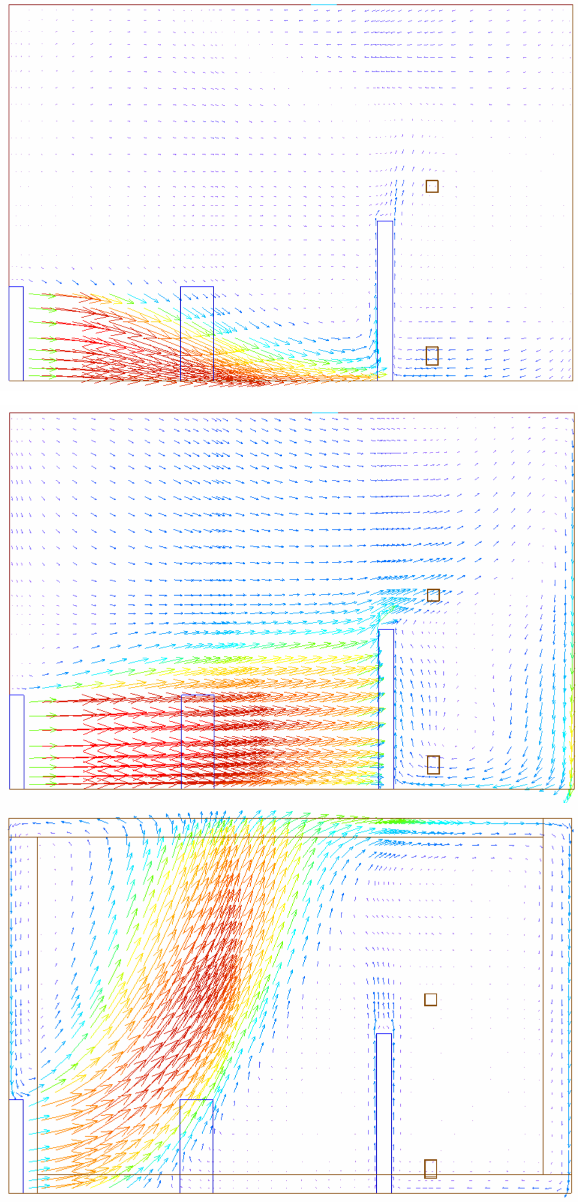


FIG. 22: Influence of supply air temperature in displacement ventilated room (xy-plane). Visualisation of the influence of the supply air temperature compared with the room air. Top: Cold supply air. Centre: Isothermal supply air (same temperature as the room air). Bottom: Warm supply air (See Fig. 20 for geometry details).

The following animations show the flow field visualised on stills in Fig 22.

Animation 3 http://it.civil.auc.dk/itcon/animation3.wmv (0.7 MB)

Animation 4 http://it.civil.auc.dk/itcon/animation4.wmv (0.6 MB)

Animation 5 http://it.civil.auc.dk/itcon/animation5.wmv (0.6 MB)

Animations 3, 4, 5 and 6 can be downloaded as high resolution avi files from http://it.civil.auc.dk/itcon

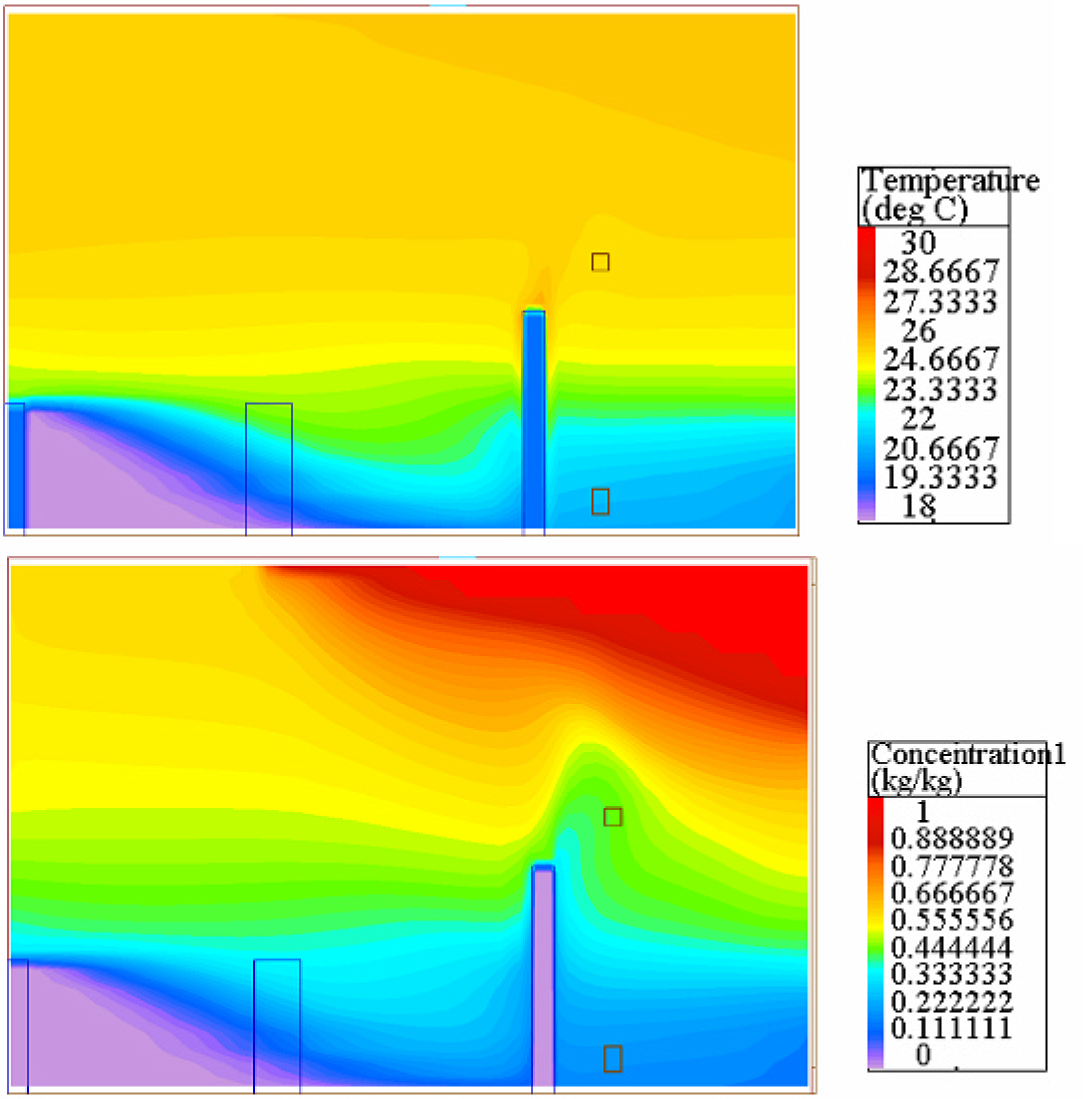


FIG. 23: Top: Temperature distribution in the xy symmetry plane of the displacement ventilated room (stratified flow field). Bottom: Concentration distribution in the symmetry plane in case of a warm point contaminant source. The concentration is made dimensionless, thus, it corresponds to the exhaust concentration. If the room was fully mixed the value would be 1 for the entire room.

The following animation visualises how the clean supply air enters the lower part of the displacement ventilated room and spreads out along the entire floor – almost like water – and displaces the contaminant upwards where it is exhausted through the return opening.

Animation 6 http://it.civil.auc.dk/itcon/animation6.wmv (0.6 MB)

5.6 Measurements from field study, Bang & Olufsen HQ, Denmark

Measurements from an office building are used to give further input from a real life application and as part of it obviously also to teach the students how to measure the performance of ventilation. In the HELE environment an excursion to the building will be an important activity. If this excursion is performed at an early stage of the teaching it may form a common frame of reference throughout the course. This may comprise both practical application, introduction to the principle by smoke visualisation, measurements (evaluation of methods and models) and a possibility to feel on your own body what it is (displacement ventilation) and maybe probably experience some of the potential pros (e.g. high indoor air quality) and cons (e.g. draught along the feet). The B&O headquarter in Denmark is used as a case study, see Fig. 24.

FIG. 24: Top: B&O Headquarter, Denmark. Bottom: Close up of inlet openings.

The building is ventilated by displacement ventilation. ICT has been applied in Fig. 25 to visualise how the airflow is intended to pass through the building. The arrows are used to show the flow direction as well as the air temperature, blue indicates colder air and red indicates warmer air. In stead of lengthy explanations this kind of visualisation clearly and efficient communicates for experts as well as non-experts the whole idea of the ventilation system.

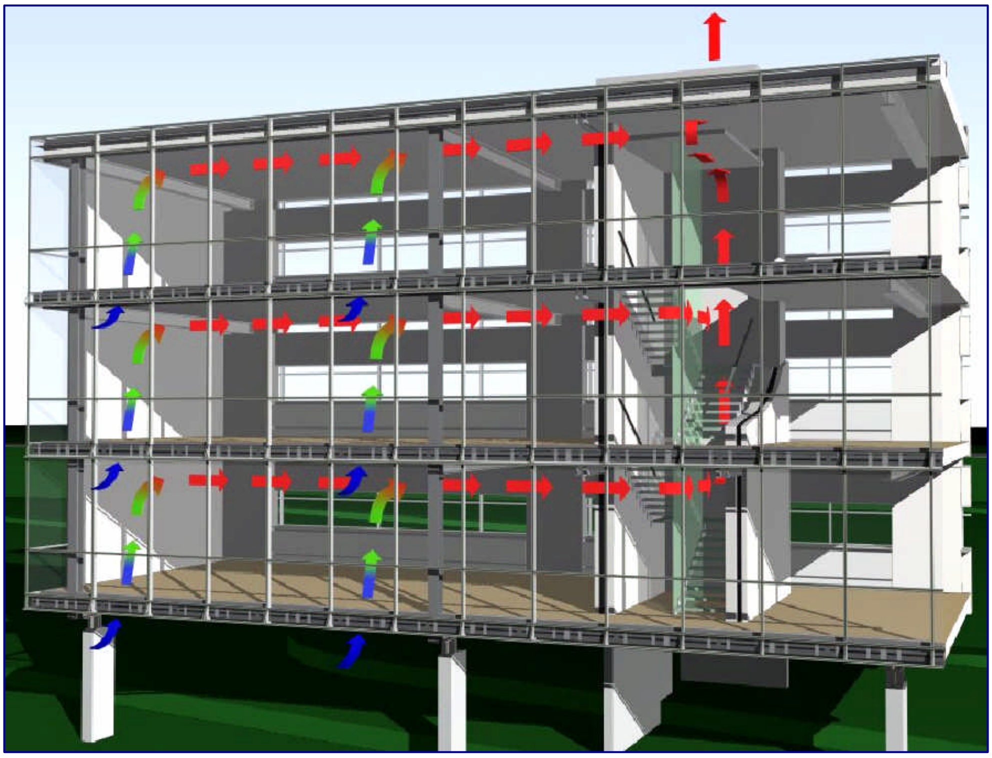


FIG. 25: Outline of airflow in B&O HQ building. Courtesy of Birch & Krogboe, Consultant Engineers, Denmark.

As a supplement to the visual inspection of the building (Fig. 24) and the ICT supported visualisation of the airflow (Fig. 25) measurements are made to quantify the airflow and ventilation effectiveness (Brohus et al., 2003). Fig. 26 shows some of the measurement equipment to perform tracer gas measurements. Airflow is by nature invisible; to examine the flow path qualitatively smoke visualisation may be applied. If quantitative assessment is required measurements may be performed.

Some results are presented in Fig. 27 comprising CO2 measurements during one day. Further treatment of the data indicates relatively high ventilation effectiveness which corresponds well with the figures that may be expected for this kind of ventilation system. In this way theoretical considerations may be taken from the classroom to the field and by full-scale real life measurements the theory may be supplemented by results from practise. This has the potential to create a deep understanding both in terms of verification of “classroom theory” and it may at the same time reveal inherent uncertainties and difficulties in practical application and, thus, initiate further discussion and reflection leading to a critical examination of the previously gained knowledge.

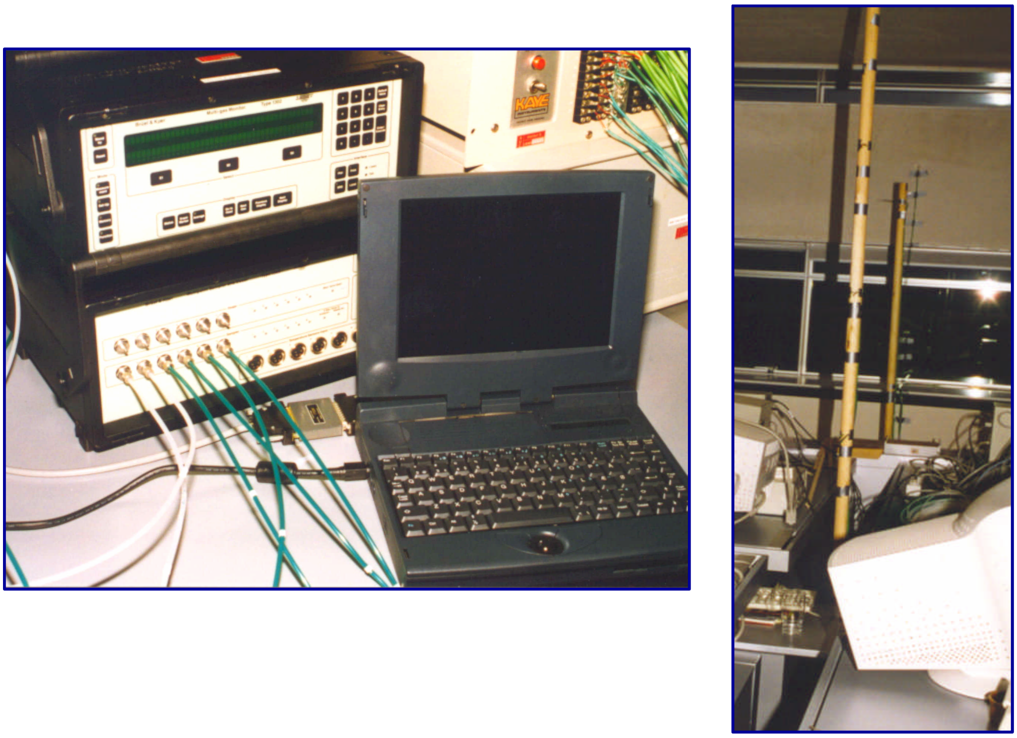


FIG. 26: Measurement equipment applied for the tracer gas measurements at the B&O building. The measurements are used to verify and quantify the airflow suggested in Fig. 25.

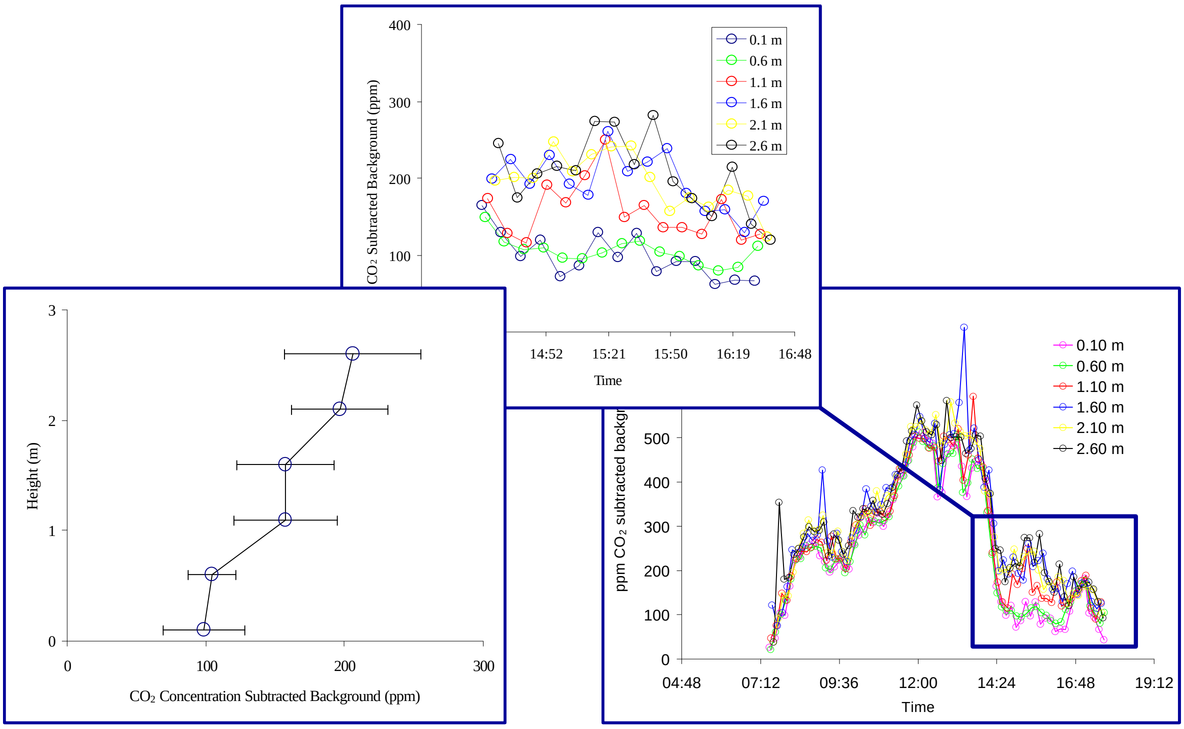


FIG. 27: Results from concentration measurements. CO2 measurements are performed at different heights in the displacement ventilated open plan office at the B&O building. Further treatment of data indicates relatively high ventilation effectiveness as assumed in theory and qualitatively suggested in Fig. 25. For further details, see (Brohus et al., 2003).

6. DISCUSSION AND CONCLUSION

Taking a starting point in a course in Ventilation Technology this paper discusses the application of ICT supported learning in the area of fluid mechanics education. It comprises past experiences and lessons learnt as well as prospect for future development in the area. A model is presented that describes a high efficiency learning environment – the so-called HELE model - where ICT plays an important role. The model explains how ICT may be used actively in the learning environment to increase efficiency in the learning process.

Traditionally, education in Ventilation Technology has been a combination of teacher performance at the blackboard combined with student exercises by paper and pencils. In order to increase learning efficiency it has been tried to make use of several tools for knowledge transfer ranging from the traditional blackboard over physical demonstrations of air flow in a full-scale laboratory mock-up to Virtual Reality demonstrations. Students have different ways of understanding a certain topic, using a broad range of tools for knowledge transfer facilitates deep understanding and increases learning efficiency.

Air flow is by nature invisible and represents a further challenge in the effort of providing sufficient understanding of typical flow patterns and behaviour of room air flow. An example of visualisation of room air flow by means of Computational Fluid Dynamics is presented by vector plots, flow fields and movies. It is discussed how different display systems like low-cost VR (e.g. active and passive stereo viewing) and high-cost VR (e.g. CAVE) can be applied and gained experiences are reported.

It is our experience that a high level of ICT-support gives some enhanced possibilities to explain certain elements of fluid flow. The combination of stereo viewing and real-time interaction with animated particle tracks and streamlines is an efficient way to understand complex three-dimensional structures. However, it is important to be aware that people can not keep concentrated for a very long time in a virtual environment with the current technology. It is a challenge to keep focus and make students remember the core issue in an environment with great possibilities for impressive “special effects”. In the fascination of the technological possibilities the students may be surfeited with such “special effects”, and there is a risk that they may miss the real message.

To obtain an efficient learning curve, the supervisor must choose the right tool or method for the right purpose at the right time, and the students must have time for reflection and to process the information between the teaching events. It is found that a combined application of various tools (methods) for knowledge transfer increases learning efficiency, for instance it is seen that a combination of physical experiments in laboratory and virtual experiments by computer simulation has a high level of synergy. The presented HELE model describes the teaching method and the pedagogical means. It explains how different learning domains – physical as virtual – may be combined to form a high efficiency learning environment.

7. REREFENCES

Barajas, Mario 2002: Monitoring and Evaluation of Research in Learning Innovations (MERLIN). Final Report of project HPHA-CT2000-00042 funded under the Improving Human Research Potential & the Socio-economic Knowledge Base Directorate General Science, Research and Development, EUROPEAN COMMISSION

Bjerg, B., Morsing, S., Svidt, K., Zhang, G. 1999: Three-dimensional airflow in a livestock test room with two-dimensional boundary conditions. Journal of Agricultural Engineering Research, Vol. 74, No. 3, pp 267-274.

Brohus, H, 1997: “Personal exposure to contaminant sources in ventilated rooms.” Ph.D. Thesis Aalborg University. No. of pages: 267 p. ISBN/ISSN: 0902-7953 (R9741), Department of Building Technology and Structural Engineering, Aalborg University, Denmark. (can be downloaded from http://iee.bt.aau.dk)

Brohus, H. and Nielsen, P.V., 1996: “Personal Exposure in Displacement Ventilated Rooms”, Indoor Air, Vol. 6, No. 3, pp. 157 - 167

Brohus, H., Frier, C., Hendriksen, O.J., Heiselberg, P., 2003: Measurement of Hybrid Ventilation Performance in an Office Building, The International Journal of Ventilation, Vol. 1, HybVent - Hybrid Ventilation Special Edition, ISSN 1473-3315, pp. 77-88.

Christiansson P., Svidt K., Skjærbæk J.O., Aaholm R.: "User requirements modelling in design of collaborative virtual reality design systems". International Conference on Construction Information Technology. Mpumalanga, Soth Africa, 30 May - 1 June 2001. (pp. 40/1 - 40/12).

Christiansson P., 1999, " Experiences from Design and Use of IT Supported Distributed Learning Environment". Civil Engineering Learning Technology in Cardiff. (edited by R M Lloyd & C J Moore). Thomas Telford Ltd. London.. ISBN: 0-7277-2839-3. (pp. 29-42). 3rd AECEF International Symposium (Association of Civil Engineering Faculties with participation of civil engineering faculties from non-European countries). CELTic 1999. 8-10 September 1999, Cardiff.

Fibiger, B. 2002: Didactic design of virtual learning environments – Modes of communication. In Dirckinck-Holmfeld, L. and Fibiger, B 2002: Learning in Virtual Environments. Published by Samfundslitteratur, Denmark, ISBN 87-593-0862-1.

Geer, R., Barnes, A., 2001: “Teaching and Learning through technology-mediated interaction”. In Watson, D and Andersen, J., 2001: Networking the learner – Computers in education. Proceedings of IFIP TC3, Seventh IFIP World Conference on Computers in Education WCCE 2001, Copenhagen, Denmark. Kluwer Academic Publishers.

Giallorenzo, V., Banerjee, P., Conroy, L., Franke, J. 1999: Application of virtual reality in hospital facilities design. Virtual Reality, Vol.4 Issue.3, pp. 223-34. Springer-Verlag 1999.

Haynes, M and Anagnostopoulou, K, 2002: Virtual learning environments as tools in learning and teaching. In Fallows, S and Rakesh, B: 2002: Educational Development through Information and Communications Technology. ISBN 0749435658.

Hutchings, M. 2002: Computer mediated communication: impact on learning. In Fallows, S and Rakesh, B: 2002: Educational Development through Information and Communications Technology. ISBN 0749435658.

Knezek, G., Christensen, R., 2001: “Impact of new information technologies on teachers and students”. In Watson, D and Andersen, J., 2001: Networking the learner – Computers in education. Proceedings of IFIP TC3, Seventh IFIP World Conference on Computers in Education WCCE 2001, Copenhagen, Denmark. Kluwer Academic Publishers.

Launder, B.E. and Spalding D. B., 1974: The Numerical Computation of Turbulent Flows. Computer Methods in Applied Mechanics and Engineering 3, pp 269-289, 1974.

Lerche Nielsen, J, 2002: The implementation of information and communication technology in project organised studies. In Dirckinck-Holmfeld, L. and Fibiger, B 2002: Learning in Virtual Environments. Published by Samfundslitteratur, Denmark, ISBN 87-593-0862-1.

Machover, C., Tice, S.E. 1994: Virtual Reality. IEEE Computer Graphics and Applications, Vol. 14, Issue 1, 1994, pp. 15-16.

Nielsen, P.V. 1974: Flow in Air Conditioned Rooms. Ph.D. Thesis. Danish Technical University, Lyngby, Denmark, 1974.

Qvist, P., 2003: Defining the Problem in Problem-Based Learning, The CLP Group, Departmen of Development and Planning, Aalborg University. http://www.but.auc.dk/~pal/abz/problemet_ver1uk.pdf

Schroeder, R. 1993: ‘Virtual reality in the real world: history, applications and projections’, Futures, Vol. 25, Issue 9, pp. 963-973, 1993.

Stuart, R. 2001: Design of Virtual Environments. Barricade Books; ISBN: 1569802076, 2001.

Sutherland, I. 1965: The ultimate display. Procedings of International Federation of Information Processing Congress, 1965, pp. 506-508.

Svidt, K. 1994: Investigation of Inlet Boundary Conditions for Numerical Prediction of Air Flow in Livestock Buildings. Proceedings of RoomVent'94, Fourth International Conference on Air Distribution in Rooms, Kraków, Poland, June 15-17, 1994.

Svidt, K., Heiselberg, P., Hendriksen, O.J. 1996: Natural Ventilation in Atria - A Case Study. Proceedings of RoomVent'96, Fifth International Conference on Air Distribution in Rooms, Yokohama, Japan, July 17-19, 1996.

Svidt K., Heiselberg P., Nielsen P.V. 2000): Characterization of the airflow from a bottom hung window under natural ventilation. Proceedings of ROOMVENT 2000, International Conference on Air Distribution in Rooms, July 2000, Reading, UK, pp. 755-760.

Svidt K., Bjerg B., Dorf Nielsen T., 2001: "Initial studies on Virtual Reality Visualization of 3D airflow in ventilated livestock buildings". AVR II & CONVR 2001. Conference on Applied Virtual Reality in Engineering & Construction Applications of Virtual Reality. (eds: O. Tullberg, N. Dawood, M. Connell. 201 pp.) Gothenburg October 4-5, 2001. (pp. 176-181).

Vince, J., 2004: Introduction to Virtual reality. Springer 2004.

Yu, P.K., Chau, K.W., 2002: “A web-based computer-aided learning package on pipe flow”. In Kwan, R. et. al. 2002: Web based learning: Men and Machines. Proceedings of the First International Conference on Web-based Learning, August 2002. World Scientific Publishing. ISBN: 981-238-126-0.