From Laboratory of Heating and Ventilation to International Centre for Indoor Environment and Energy

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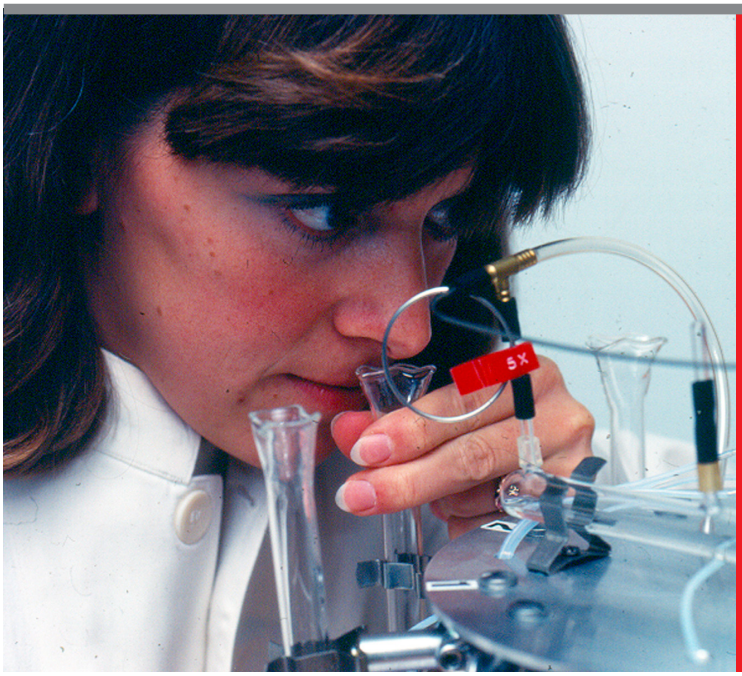

Gunnar Langkilde

A historical overview on the occasion of 125-years for an independent chair in Heating and Ventilation and 75th anniversary of the Laboratory of Heating and Ventilation

Department of Civil Engineering

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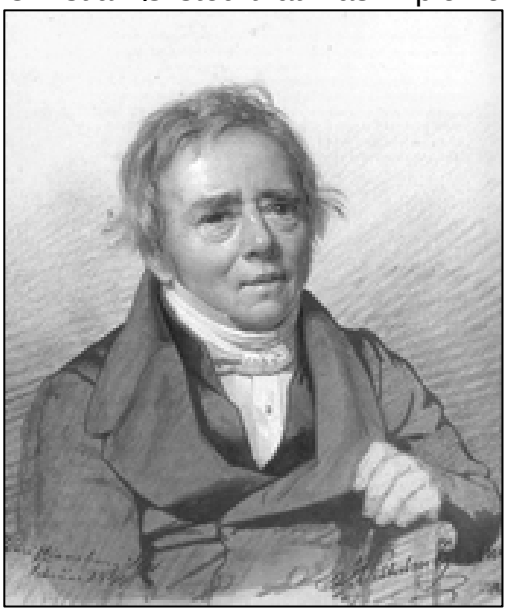
The establishment of the Polytechnic, 1829

In the beginning of the 1800s there had been several approaches for establishing an engineering school in Denmark, but it was the proposal of the Danish physician Hans Christian Ørsted that was implemented in 1829 with the establishment of the Polytechnic.



Hans Christian Ørsted.

The institution was housed in some buildings in downtown Copenhagen in the area between Studiestræde and St. Pederstræde. Ørsted taught physics and studied magnetism and carried out many experiments. To assist him with these experiments, Ørsted employed in 1834 a student named L. A. Colding. It was Colding, who later became the first teacher of heating and ventilation, but first a little about what he accomplished before then. Colding was much inspired by Ørsted and developed his own theories about energy transfer. Colding formulated the Law on Energy Conservation simultaneously and independently of Joule, who is well known to have taken the credit for it, and even has a unit named after him. Colding presented his theories at the fifth Meeting for Scientists in Copenhagen in 1847. He also constructed an apparatus, now exhibited in the Danish Technical Museum, to determine the mechanical equivalent of heat. The apparatus consisted of a bar which was heated by mechanical friction and the increased temperature was ascertained by measuring the increased length of the friction bar. On Colding's gravestone in the cemetery "Assistents Kirkegård" is the inscription "The Forces of Nature are Ever lasting". Colding was appointed inspector of waterworks (1847) and later (1857) civil engineer in Copenhagen.

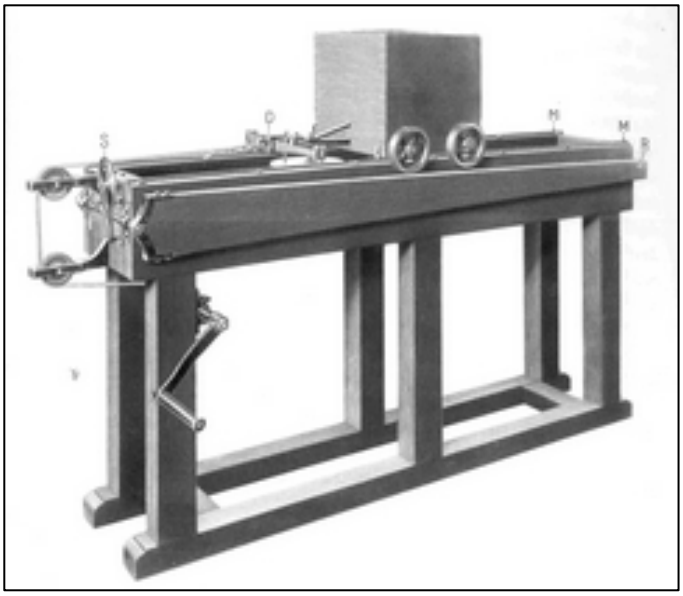
It was during this period that cholera raged in Denmark and Colding diagnosed, together with the chemist Julius Thomsen, who later became rector of the Polytechnic, that cholera was spread through the drinking-water. He arranged for a radical expansion of water and sewer systems in the capital.

Ludvig August Colding.

The first teachers of heating and ventilation

In 1865 the chair in the combined disciplines "Heating, ventilation, sewer, water and gas systems" was established and Colding taught there for nearly 20 years. In 1869 he received the title of professor. For his teaching, Colding had a collection of handwritten notes, which are now saved in DTU's historical archive and entitled "The general principles

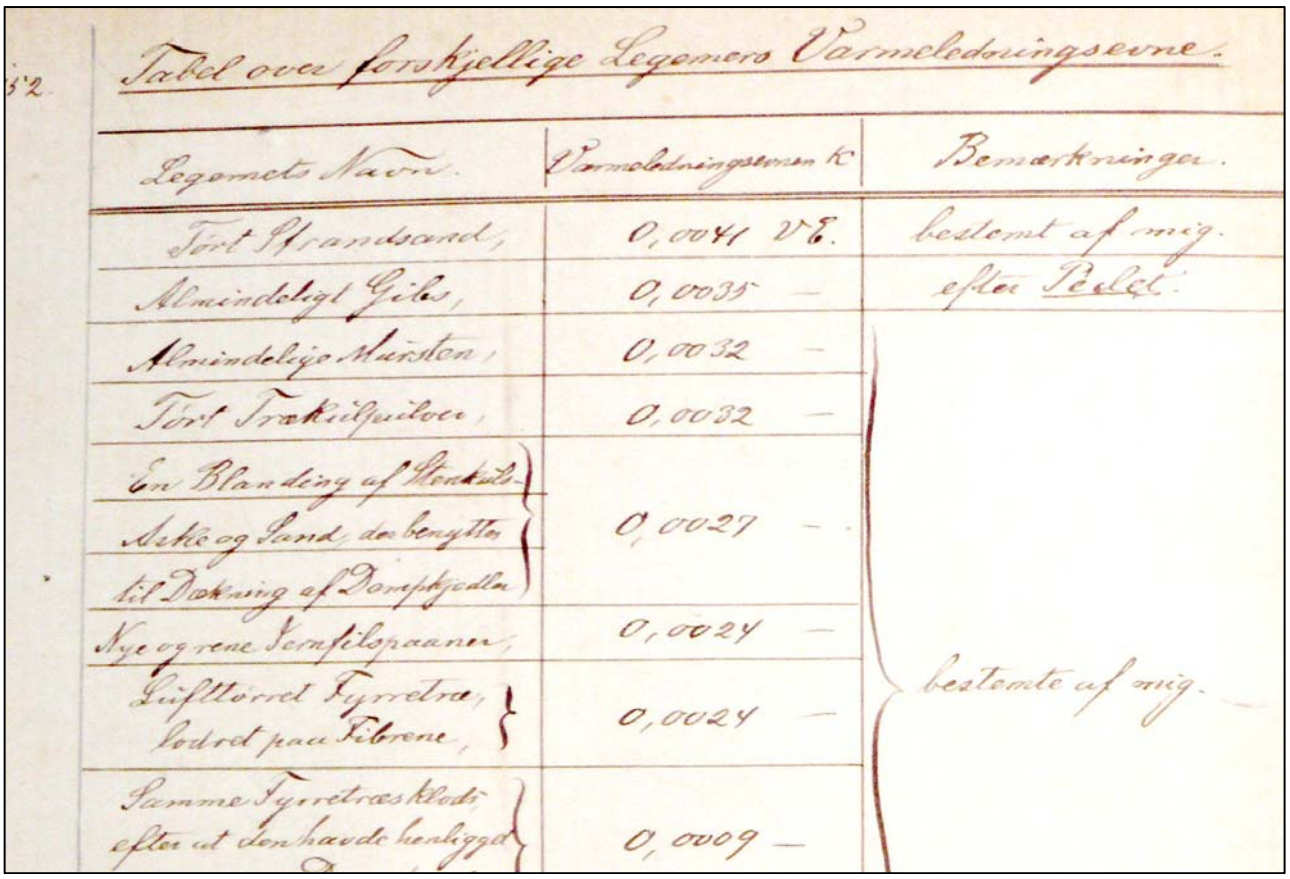
concerning the discharge of harmful water, Supply of Water and Gas, and Installation of Heating and Ventilation".



Colding's apparatus to determine the mechanical equivalent of heat.

Independent chair

In 1885 the course Heating and Ventilation was established as an independent chair, since the subject water installations and drainage was separated and later came to be called Technical Hygiene. At Berlin's Technical University, Hermann Rietschel established a few weeks earlier a chair in Heating and Ventilation. Berlin managed therefore, to have the world's first independent chair in the subject. Simultaneously with the establishment of the chair Christian Ramsing was appointed new teacher, but was in the post only for five years, after which he devoted himself to his engineering firm. Later in 1906 he received the title of professor. There are no notes or other teaching material left from Ramsing.



Tabel over forskjellige Legemers Varmeledningsevne.

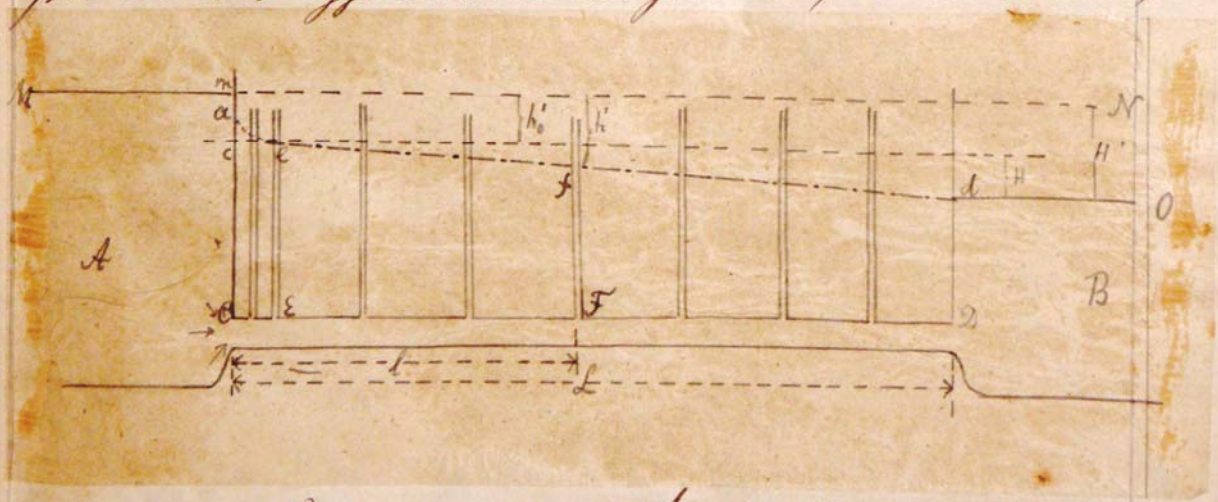
Legemets Navn.	Varmeledningsevnen k	Bemærkninger.
Fort Strandsand,	0,0041 V.E.	bestemt af mig.
Almindeligt Gibs,	0,0035 —	efter Peclet.
Almindelige Mursten,	0,0032 —	bestemte af mig.
Fort Trækulspulver,	0,0032 —	
En Blanding af Stenkuls-Aske og Sand, der benyttes til Dækning af Dampkjedler	0,0027 —	
Nye og rene Sømspilspaaner,	0,0024 —	
Lufttørret Fyrretræ, ledet paa Fibrene,	0,0024 —	
Samme Fyrretræsklods efter at den havde henligget	0,0009 —	

Part of a table with heat conduction coefficients from Colding's original notes from app. 1875. Many of the values are determined by himself.

De almindelige Love for flydende Legemer, Bevægelse i ensartede Ledninger, der have et konstant Tværsnits-Areal.

Naar et flydende Legeme strömmer igjen-
nem en Ledning fra en Indløbsbeholder til en Ud-
løbsbeholder, lider det en Modstand i Ledningen,
som voxer med Kvadratet af Fluidets Strömnings-
hastighed. Til at overvinde den Modstand, som
Ledningen frembyder, udfordres der en Arbejdsmæng-
de, og denne Arbejdsmængde maa Fluidet afgive
efterhaanden som det passerer Ledningen.

Betragte vi nedenstaaende Figur og tænke
vi os A at være Indløbsbeholderen og B Udløbs-
beholderen samt, at Fluidet, der strömmer over
fra A til B igjennem Ledningen C D, t. Ex. er Vand,



saa maa Vandspejlet, der i Indløbsbassinet ligger i

Page from Colding's handwritten lecture notes.

The institution moved to Sølvgade

In 1889 the institution received a much needed expansion when the new buildings at Sølvtorvet came into use.

The Polytechnic at Sølvtorvet app. 1900.

Erdmann Peter Bonnesen.

In 1892, Erdmann Peter Bonnesen became responsible for teaching in Heating and Ventilation and was from 1902 professor in the subject. He published in 1901 a comprehensive textbook of 300 handwritten pages with an appendix of tables, charts and drawings. The book was divided into sections, namely Heating, Ventilation and Measuring Instruments. The section on ventilation, which was only 27 pages, covered mainly the calculation of air ducts with natural buoyancy, as electric motors at that time had just begun to be used in ventilation technique. Automatic control was not yet known. Bonnesen taught for 27 years until 1919, when he resigned at the age of 73 years. The vacant position after Bonnesen was filled by FC Becker in 1919 after four qualified applicants had given test lectures. Becker was chosen partly because he had shown that he was able to carry out scientific work but also because he was in possession of good teaching abilities. Apart from his teaching profession he had his own consulting engineering firm and could in this excellent way combine theory and practice. He received the title of associate professor in 1927 and full professor in 1935.

Naar vi opvarme vore Værel-
ser, selv om det sker med den mest gam-
meldags Ovn, falder de færreste paa, hvor-
ledes denne tilsyneladende simple Hand-
ling i Virkeligheden er sammensat af
en Række temmelig komplicerede Fæno-
mener; og sker Opvarmningen ved
Hjælp af et Centralapparat, bliver Proces-
sen naturligvis endnu mere sammen-
sat. Det er Opgaven her at rede disse Fæ-
nomener saaledes ud fra hverandre,
at man kan komme til en Beregning
af Varme- og Ventilationsanlæg.

Faget er i det hele taget vel egnet
til at underkastes teoretisk Behandling,
saa længe man kan regne med ideale
Forhold, men de fundne Resultater maa
anvendes med Skønsomhed, naar de
føres ud i Praksis, hvor Forholdene

First part of the preface of Bonnesen's handwritten textbook. Today's students could learn from the neat handwriting.

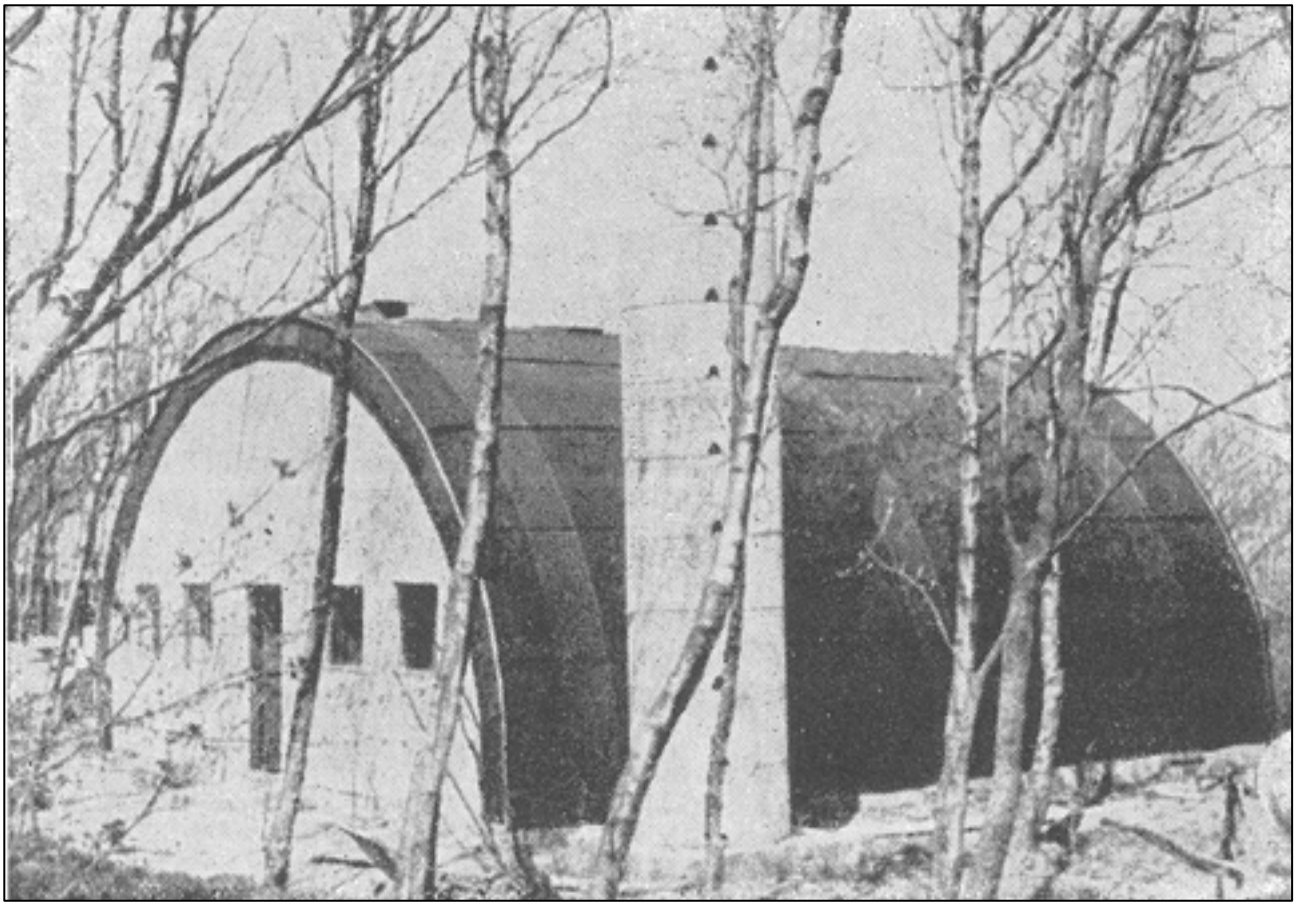
As time went by, the areas at Sølvtorvet also became too cramped so expansion was needed. It took place at Østervoldgade where in 1929, 100 years after the establishment of the Polytechnic, the foundation stone was laid.

The establishment of the Laboratory of Heating and Ventilation

At the same time, the name of the Polytechnic was changed to “Technical University of Denmark”. The expansion came to drag on for many years due to the general economic situation and World War II, so the official inauguration took place first in 1954.

Laying of the foundation stone for the building work at Østervoldgade in 1929. The rector P. O. Pedersen stands at the end of the table.

Becker struggled for many years to expand the education and also the opportunities to perform experimental work. Not until 1935, 50 years after the establishment of the profession as an independent chair, did Becker succeed by creating an independent laboratory "Laboratory of Heating and Ventilation" in the new buildings on Østervoldgade.
The funds, however, were small, so it was still mostly theoretical research that was performed. One of Becker's major interests was to determine heat loss from buildings, and he erected an experimental building with very little heat loss, or, as he called it, an "Almost Heat Tight” house. The cost was covered from his own pocket. The building consisted of cylindrical half shells with insulating peat dust between. To heat the house he constructed a windmill. This was, however, never finished. Becker continued as professor and director



F.C. Becker's "Almost-Heat-Tight" house, that he built in North Zealand on his own money. The tower in front was designed for a windmill.

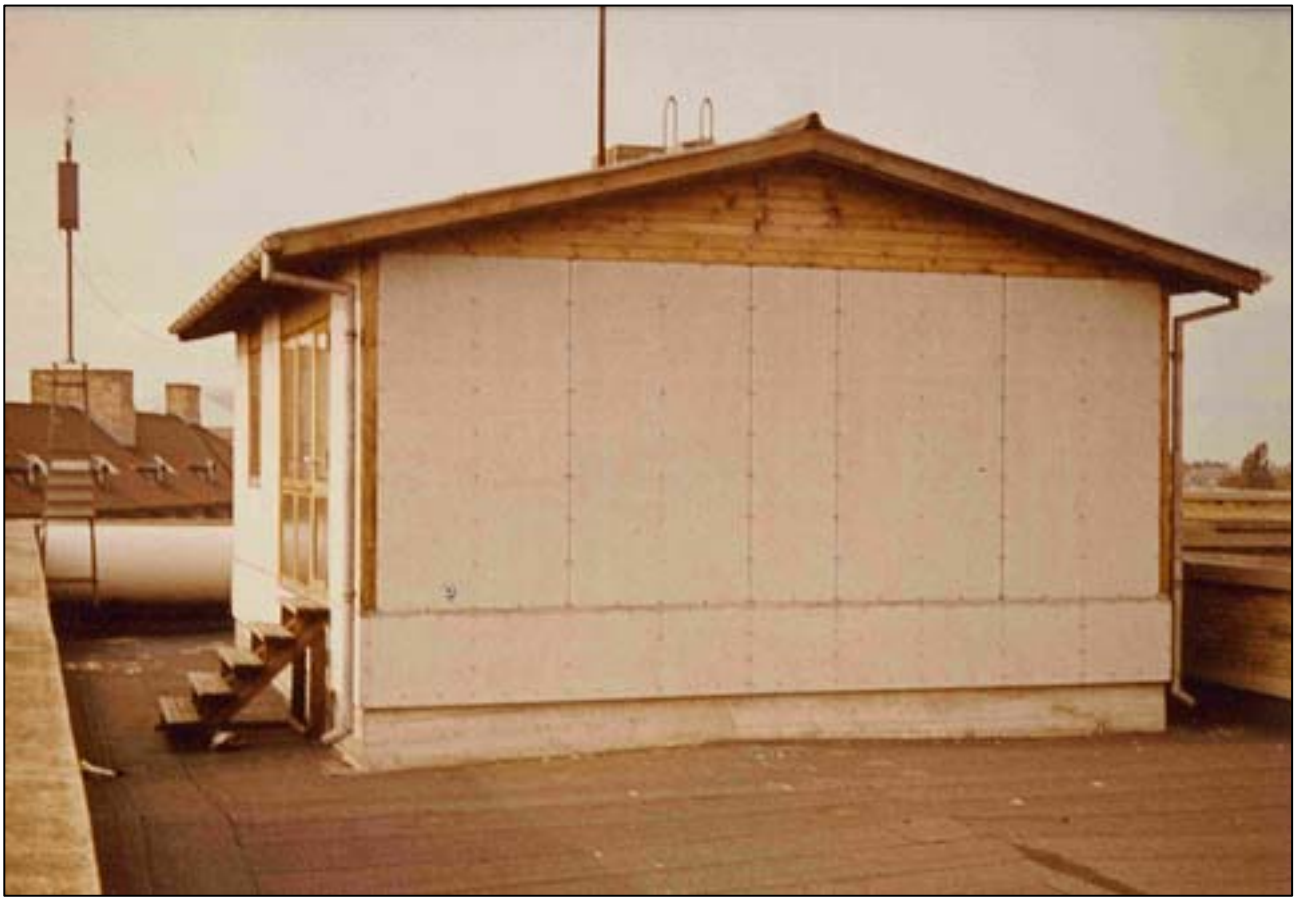
of the laboratory until he was 70 years in 1953. During the entire period from 1937 Becker had an assistant at his side, namely N.F. Bisgaard, who assisted with both teaching and research. Bisgaard's main interest was the relationship between heat by convection and radiation. He constructed instruments to measure thermal radiation and wrote a doctoral thesis on directional thermal radiation fields.

On Becker's retirement in 1953 Bisgaard took over the leadership of the Laboratory and was also appointed professor. In subsequent years the Laboratory was the beneficiary of Marshall aid, so it was possible to provide new laboratory equipment and measuring instruments. One focus area was now boiler and burning systems, areas which were also major topics for Sven Hadvig who had studied a few years at Massachusetts Institute of Technology in the United States. Hitherto, coal and coke were the main fuels for heating, but now oil-fired burners came on the market, so he began to study oil burners and boilers.

N. F. Bisgaard.

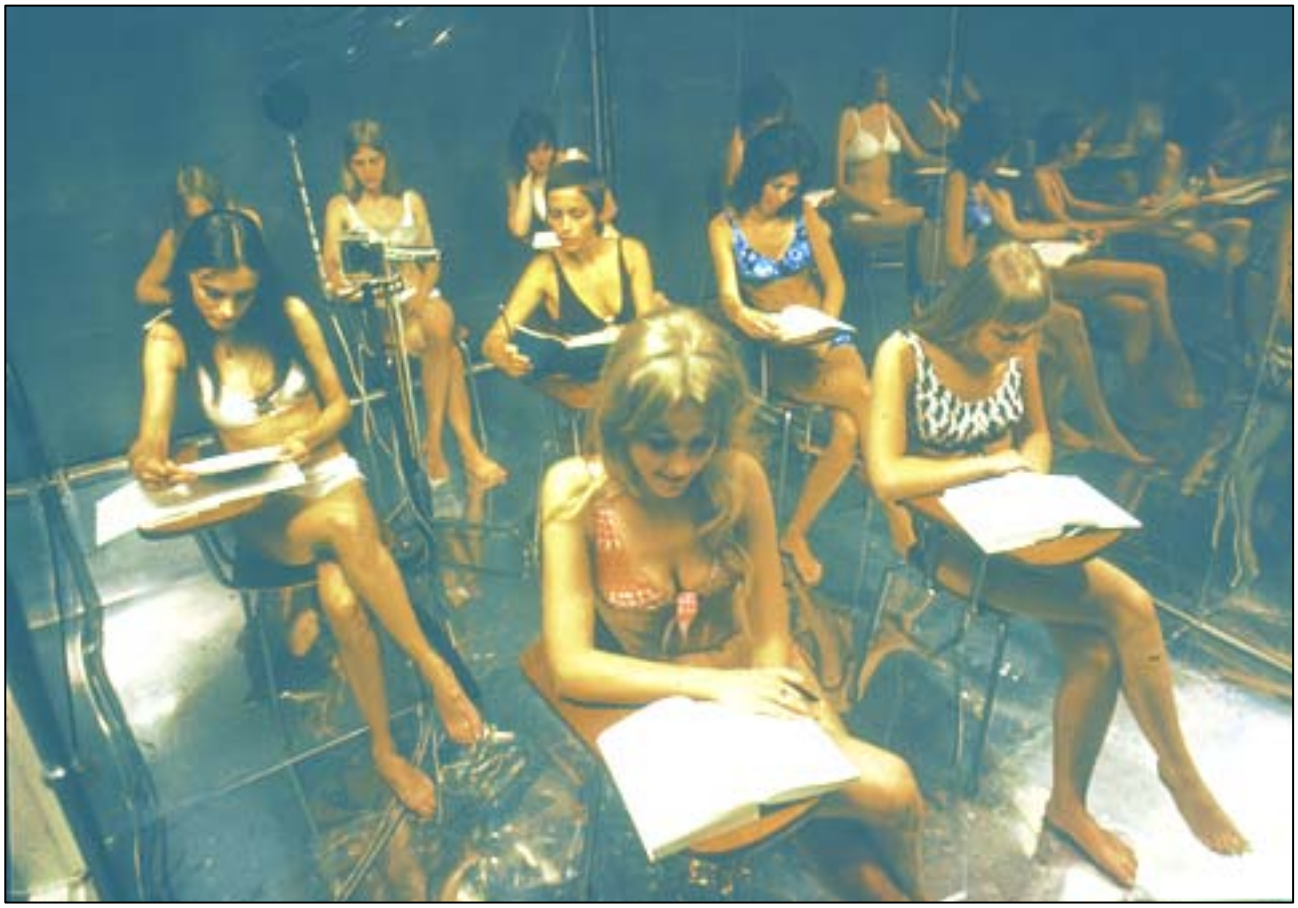
The Suez Crisis 1956-57 resulted in a shortage of oil and was followed by severe price increases. To meet the high cost of heating our homes, Vagn Korsgaard proposed that the possibilities of improving housing insulation should be investigated. His persistent approaches to ministries and parliament resulted in a large grant in 1959. The Thermal Insulation Laboratory was a reality and was separated from the Laboratory of Heating and Ventilation as an independent laboratory. The Thermal Insulation Laboratory was built on an area in Hjortekær where besides laboratory facilities an experimental building was built, that was designed to investigate different types of building envelope. An experimental building, that was built on the roof of one of the buildings on Østervoldgade was also moved to Hjortekær. This building was used for studies of thermal insulation.

Instrument for measuring radiation, constructed by Bisgaard.



Experimental house on the roof of DTU at Østervoldgade. The house was moved to Hjortekær.

With the employment of P. Ole Fanger in 1959, research in indoor environment at the laboratory was started, especially after he had studied in 1966-67 in the U.S. where he had conducted numerous experiments with people in climate chambers. In the basement at Østervoldgade, the first climate chamber for study of thermal comfort was built.



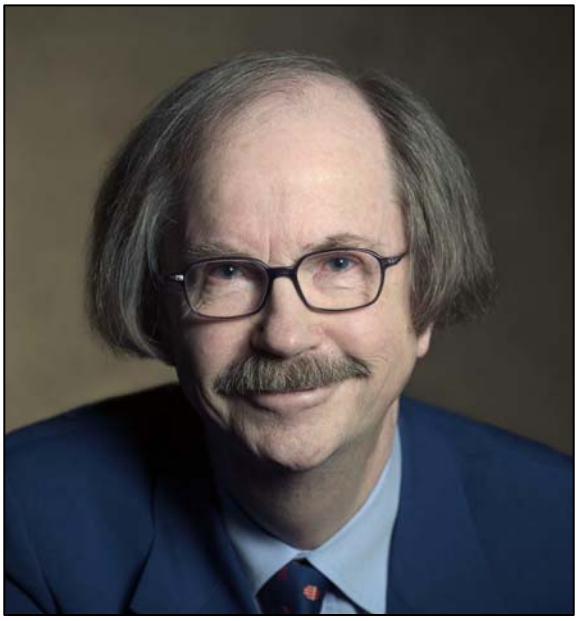
Experiments in the first climate chamber at Østervoldgade using human subjects.

Three different versions of the Comfort meter, developed by Thomas Lund Madsen. The one to the right was in production at Brüel&Kjær.

Moreover in the laboratory an arrangement was constructed for determining view angles relative to persons in relation to differently oriented surfaces. Experiments with view angles

and experiments in the new chamber, as well as the previous studies in the U.S., formed the basis for his doctoral thesis "Thermal Comfort" published in 1970. In the thesis, Fanger derived the comfort equation, which predicts the degree of thermal comfort on the basis of the values of the thermal environmental parameters. Fanger was appointed professor in 1977.

At the Thermal Insulation Laboratory, Thomas Lund Madsen developed a comfort meter that could measure directly the degree of thermal comfort. The instrument is based on Fanger's comfort equation.



P. Ole Fanger.

DTU moves to Lyngby and the Laboratory is renamed.

Although a possible expansion with more buildings in the neighbourhood around Øster-voldgade was planned, it was recognized that with the rapid technical development taking place, that would not be enough. Therefore at an early stage, sites outside Copenhagen were considered for a total relocation of the colleges. The choice was, as we know Lyngby. The construction took place primarily in the years 1960 - 1974. The laboratory relocated in 1970 and on that occasion its name changed to Laboratory of Heating and Air Conditioning. The relocation made possible a significant expansion of the area for the laboratory, both for offices and testing facilities. There was thus

The Lundtofte Campus. The lab is close to the tall chimney.

one dedicated test area for indoor climate research, one for boiler and combustion research and one for research on ventilation.

Boiler and Combustion Research in Lyngby

Today, boiler and combustion research at the lab is closed down. However, part of combustion research has been taken over by the Department of Chemical Engineering, but prior to that shift, numerous research projects were carried out under the management of Sven Hadvig. Hadvig had studied thermal radiation in combustion processes during his stay at the well-known MIT in the U.S. In Lyngby, Hadvig conducted studies of combustion processes, not only in traditional boilers, but also in more specific combustion processes such as fluidized bed combustion. In connection with the discovery of gas in the North Sea, gas firing became popular, and Sven Hadvig developed new condensing boilers with very high efficiency for gas firing.

In connection with fire research a number of spectacular experiments took place on the DTU area. Large quantities of plastic boxes were set on fire with heavy smoke as a consequence. There had been a few heavy fires in a couple of one-storey schools, and to study fire development, the lab was given permission to ignite the remains of one of the already burned down schools. In connection with the demolition of part of the inner Nørrebro area, the Laboratory was likewise allowed to perform pyromania, as a number of stairwells were ignited to study the effect of fire retardant paints. It was obviously with permission and presence of the fire brigade.

One area where Denmark has been in evidence internationally is district heating. For a long period Benny Bøhm was research professor at the Laboratory with district heating as his subject, and he carried out several projects on the optimization of various district heating systems.

Another "Zero Energy House"

Twenty-five years after Becker built his "Almost Heat Tight" house, a "Zero Energy House" was constructed in DTU's northern area, where P. Kjerulf-Jensen took part in the design of heat recovery systems. The Thermal Insulation Laboratory was responsible for the design and construction of the house, which was heated only by solar energy and was therefore equipped with a giant heat storage tank.

Zero-Energy House at the northern area of DTU.

The enormous heat storage tank.

The new chamber that was built in connection with the relocation to Lyngby was designed to study the thermal indoor climate, which had hitherto been the main focus area for indoor climate research. Air quality and ventilation requirements came to be new research areas, that were introduced. To carry out laboratory experiments with subjects, two new climate chambers were built specifically for the study of air quality. Two identical climate chambers

Air quality experiments in stainless steel climate chambers.

in stainless steel were built, thus providing the opportunity to compare two different situations by moving from one chamber to the other. As a result of the air quality research, Fanger presented in 1987 two new units, "olf" and "decipol", for the quantification of air quality. The presentation took place in 1987 at the international conference “Indoor Air '87” in Berlin.

Establishment of a centre for indoor environment.

Fanger possessed the ability to obtain funds for the Laboratory from external sources and

Three new climate chambers ready for new research projects.

as a culmination, a 10-year grant of approx. 7 mill. DKK per year was given from the National Technical-Scientific Research Foundation in 1998. It was in this context that the

At the inauguration of the newest chambers in 2001 there were prominent guests, from left: Rector of DTU Hans Peter Jensen, Minister of Education Margrete Vestager, Chairman of the Board of DTU Mogens Bundgård Nielsen, DTUs Dean for Research Steen Krenk and Head of the Centre P. Ole Fanger.

"International Centre for Indoor Environment and Energy" was formed. Fanger resigned in accordance with the rules in 2004 at the age of 70, but continued as a senior professor, a title he himself invented. Fanger received before his untimely death in 2006 a wide range of honours and honorary degrees worldwide. Today the Centre is led by Professor Bjarne W. Olesen and since 2008 has been part of the Department of Civil Engineering (DTU.Byg). The formation of the Centre and the many resources that were given made it possible once again to build new climate chambers and to intensify research, as there was also room for new research positions. New climate chambers were

Climate chambers for study of airflow in rooms. The size can be changed and it can be divided into several chambers.

built for studies of air quality but also for studies of air movement and ventilation. One result of this research is the development of personalized ventilation, a ventilation form where fresh air is blown directly to the person's breathing zone. The system was developed in conjunction with a Danish ventilation company that now has marketed the product. Another research field that gave a direct useful commercial outcome, is that of air cleaning and humidity conditions in aircraft cabins. A wide range of experiments with simulations of situations in aircraft cabins during long-haul flights has been carried out. The results of this research are used directly today in the design of the newest aircraft.
That the lab has left its imprint on the world map is attested by the many honours that Fanger brought home from all over the world and sat up on the walls of his office.

Ole Fanger's wall of fame in his office with some of the many honours from all over the world.

Historical facts about the Laboratory

Laboratory's names over the years:

1935 - 1972	Laboratory of Heating and Ventilation
1972 - 1995	Laboratory of Heating and Air Engineering
1996 - 2000	Section for Indoor Environment and Energy, Department of Energy Engineering
2000 - 2006	Indoor Climate and Energy, Department of Mechanics, Energy and Structural Engineering
2007 - 2008	Section for Indoor Environment and Energy, Department of Mechanical Engineering
2008 -	Section for Indoor Environment, Department of Civil Engineering

The "International Centre for Indoor Environment and Energy" was formed in 1998 and included at that time most of the Indoor Environment and Energy at the Department of Energy Engineering.
Today the Centre is synonymous with the Indoor Environmental Section at the Department of Civil Engineering.

Leaders of the Laboratory over the years:

1935 - 1953	F. C. Becker
1954 - 1980	N. F. Bisgaard
1980 - 1986	Ole Albrechtsen
1986 - 1994	Gunnar Langkilde
1995 - 1999	P. Ole Fanger
2000 - 2007	Geo Clausen
2008 -	Bjarne W. Olesen

Professors at the Laboratoriet over the years:

1902 - 1919	E. P. Bonnesen
1935 - 1953	F. C. Becker
1953 - 1980	N. F. Bisgaard
1977 - 2006	P. Ole Fanger
	Benny Bøhm
1996 - 2001	David P. Wyon
2004 - 2007	Jan Sundell
2003 -	Bjarne W. Olesen

The first teachers L.A. Colding and C. Ramsing received the title of professor first after they had left the university. This occurred respectively in 1869 and in 1906.

Besides this list, there is a large number of foreign professors who have been on guest stays at the lab, typically of 3 to 6 months.

PhDs in the laboratory over the years:

Previously titled Technical Licentiate.

Anders Korsgaard:	Affaldsforbrænding.
Otto Paulsen:	Undersøgelse af brandprøveovnes termiske påvirkninger med sørlig henblik på indflydelse af ovngeometri, ovnmaterialer og fyring. 1975.
Bjarne W. Olesen:	Termiske komfortkrav til gulve. 1975.
Claus Pedersen:	Komfortkrav til luftbevægelser i rum. 1977.
Benny Bøhm:	Fully Developed Polyethylenes and Wood Compartment Fires with Applications to Structual Design. 1977.
Lars Hallgreen	Optimeret styring af klimaanlægs referenceværdier. 1981.
Allan Bang Jensen:	Wind Tunnel Modelling of Atmospheric Boundary Layers. 1981.
Henrik Holm:	Udvikling og opbygning af faciliteter til kalibrering og undersøgelser af transducere til måling af det termiske indeklima. 1986.
Geo Clausen:	Tobacco smoking and ventilation requirements. 1986.
Peter Glarborg:	Kinetisk modellering af dannelse og nedbrydning af NOx ved forbrænding af simple kulbrinter. 1987.
Niels Bjarne Rasmussen	Numerisk Modellering af Turbulent Strømning og Forbrænding i Forbrændingsrum. 1987.
Lars Gunnarsen:	Ventilationsbehov og adaption til indeluft. 1989
Philomena Bluyssen:	Air quality evaluated by a trained panel. 1990.
Atli Benonysson:	Dynamic Modelling and Operational Optimization of District Heating Systems. 1991.
Jan Pejtersen:	Forureningskilder i ventilationsanlæg. 1994.
Henrik N. Knudsen:	Modellering af indeluftkvalitet. 1994
Jørn Toftum:	Trækgener i det industrielle arbejdsmiljø. 1994.
Chinh Minh Trinh:	Turbulence Modelling of Confined Swirling Flows. 1994.
Lisbeth Groes:	The European IAQ Audit Project: a statistical analysis of indoor enviropnmental factors. 1995.
Lei Fang:	Impact of temperature and humidity on perceived air quality. 1997.
Pawel Wargocki:	Human perception, productivity and symptoms related to indoor air quality. 1998.
Genhong Zhou:	Human perception of air movement: Impact of airflow frequency and direction on the sensation of draught. 1999.
Ole Alm:	Ventilation filters and their influence on human comfort, health and productivity. 2001.
Thomas Witterseh:	Environmental perception, SBS synptoms and the performance of office work undercombined exposure to temperature, noise and air pollution. 2001
Jan Kaczmarczyk:	Human response to personalized ventilation. 2003.
Zsolt Bako Biro:	Human Perception, SBS Symptoms and Performance of Office Work during Exposure to Air Polluted by Building Materials and Personal Computers. 2004.
Radim Cermak:	Design strategies for personalized ventilation. 2004.
Gyöngyi Tamás:	Ozone Initiated Reactions and Human Comfort in Indoor Environments. 2005.
Nan Gong:	Human perception of local air movement in the tropics. 2006.

Love Per Lagercrantz:	Sensation of "Dryness" Humidity of Air, Health and Comfort. 2007.
Lars P. K. Voigt:	Navier-Stokes Simulations of airflow in rooms and around a human body. 2007.
Peter Strøm-Tejsen:	The effects of the aircraft cabin environment on passengers during simulated flights. 2007.
Kiril Naydenov:	On the association between home exposure and asthma and allergies among children in Bulgaria. 2007.
Yang Bin:	Evaluation of performance characteristics of newly developed ceiling mounted personalized and mixing ventilation system. 2009.
Kasper Lynge Jensen:	Development of a model to calculate the economic implications of improving the indoor climate. 2009.
Fadeyl Moshood Olawale:	Effects of Filters, Ventilation and Recirculation rates on Ozone Initiated Chemistry Products in Air-Conditioned Buildings in the Tropics and their effects on occupants. 2009.
Rune Vinther Andersen:	Occupant behaviour with regard to control of the indoor environment. 2009.
Zhecho Bolashikov:	Protection of occupants from airborne transmission of infectious agents by advanced air distribution systems. 2010.

Besides this list, there is a large number of foreign doctoral students who have stayed as guests at the lab, typically for ½ - 1 year duration.

This publication is sponsored by:

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