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Alternatives to mercury-containing measuring devices

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Preface

Background

With the aim of reducing the demand for mercury used in products and speeding up the substitution of mercury, the Extended Impact Assessment for the Community strategy concerning mercury indicated that it would be appropriate to introduce a Community level marketing restriction on mercury-containing measuring and control equipment for use by the general public and, with some exemptions, in the healthcare sector.

The Commission of the European Communities has 24 February 2006 presented a proposal for amending Council Directive 76/769/EEC relating to restrictions on the marketing of certain measuring devices containing mercury.

According to the Danish Environmental Protection Agency, the proposed restriction will, as regards fever thermometers and sphygmomanometers, provide a higher level of protection than the existing Danish regulation, whereas the protection level for other devices will be weakened in a lesser extent in Denmark by implementation of the Commission's proposal as indicated in the following table:

Devices	Danish regulation according to Statutory Order no. 627 of 1 July 2003	The proposal from the Commission
Fever thermometers	Not prohibited	Prohibition
Other thermometers	Prohibited, except for equipment used for calibration and laboratory use	Prohibition of sale to the general public
Sphygmomanometers	Not prohibited	Prohibition of sale to the general public
Manometers	Prohibited, except for equipment used for calibration	Prohibition of sale to the general public
Barometers	Prohibited, except for equipment used for calibration	Prohibition of sale to the general public

This study

The Danish EPA has launched this study on advantages and drawbacks of alternatives to mercury-containing equipment marketed in Denmark as part of the preparations for the amendment of the directive.

The project has been followed by a Steering Group consisting of:

- Rikke Donchil Holmberg, Danish Environmental Protection Agency
- Frank Jensen, Danish Environmental Protection Agency
- Carsten Lassen, COWI A/S
- Jakob Maag, COWI A/S

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Summary and conclusions

The investigation shows that mercury-containing manometers, barometers and thermometers, apart from certain applications in laboratories, have been totally phased out in Denmark and satisfactory, cost-efficient alternatives are available for all identified applications. For blood pressure measurements, mercury-containing sphygmomanometers are still requested by some general medical practitioners and a few hospital departments. In recent years the electronic and mechanical mercury-free devices have been improved, and devices which are validated with reference to internationally recognised protocols, are marketed at prices corresponding to the price of mercury-containing blood measurement devices. The disadvantage of electronic devices is that they for the user are a kind of "black box", and it is not easily recognisable whether they function correctly, which means that they must be checked more regularly. In spite of this, the electronic devices, which also have significant advantages, supersede mercury-containing devices for most applications concurrently with a significant improvement of the electronic devices and a drop in the price. Electronic equipment has also replaced mercury-containing devices for advanced measurements and calibration of other thermometers, manometers and barometers.

Historic consumption of mercury with measuring devices

The consumption of mercury for measuring devices in Denmark has during the period from 1982/83 to 2000/01 decreased by a factor of 100 (see table 1). The driving forces behind the decrease have partly been the development of new technologies, in particular the development of electronic devices for automatic measurements, partly been environmental concern which has also resulted in a ban of the marketing of some of the mercury-containing measuring devices.

Table 1
Mercury consumption in relation to measuring devices in Denmark

Application area	Mercury consumption (kg Hg/year)		
	1982/83	1992/93	2000/01
Fever thermometers	750	50	1.1
Other thermometers	1,300 - 1,800	100	15 - 20
Other measuring and control devices including blood measurement devices and mercury for maintenance of existing devices	430 - 630	500	10 - 50
Total	2,480 - 3,180	650	26.1 - 71.1

Thermometers other than fever thermometers

The marketing of mercury-containing thermometers other than fever thermometers is today banned in Denmark except for marketing of thermometers for calibration of other thermometers and for use in laboratories.

Alternatives for all original applications of mercury-containing thermometers are available on the market (see table 2). The price of alternatives varies significantly. Liquid-in-glass thermometers are available at the same price as mercury thermometers, whereas the price of some electronic thermometers is up to ten times the price of mercury thermometers. Electronic thermometers are widely used for all applications, because the advantages of the automatic measurements and datalogging compensate for the higher price.

Table 2
Marketed alternatives for mercury-containing thermometers in Denmark

Application area / product type	Marketed alternatives	Price of alternatives compared to mercury thermometers	Comment
Mercury-in-glass thermometers for machines, engines, boilers, etc.	Liquid-in-glass thermometer (up to 250°C)	~ same price	
	Dial thermometers (up to 650°C)	~ 2-4 times more	
	Electronic thermometers	up to 10 times more	Widely used for automatic measurements and datalogging
Mercury-in-glass thermometers for ambient air temperature measurements incl. min/max measurements	Liquid-in-glass thermometer	~ same price	
	Electronic thermometers	up to 10 times more	Used for automatic measurements, datalogging and standard equipment of weather stations
Mercury dial thermometers for remote control in the industry and on ships	Dial thermometers with capillaries with other liquid or gases	~ 2-4 times more	
	Electronic thermometers	up to 10 times more	Widely used for automatic measurements and datalogging
Mercury-in-glass glass thermometers for laboratory use	Liquid-in-glass thermometer (at 1 degree)	~ same price as ordinary Hg thermometer	
	Electronic thermometers (at 0.1 degree resolution at a wide temperature range)	Up to 10 times more than ordinary Hg thermometers ~ same price as certified Hg thermometers	Widely used for automatic measurements and datalogging

The liquid-in-glass thermometers can substitute for mercury-in-glass thermometers for most applications except for measurements in the temperature range above 250°C and for measurements in laboratories at less than 1 centigrade resolution. For high-temperature applications in the industry, the mercury thermometers are typically replaced by dial thermometers for manual reading or by electronic thermometers. For high-resolution measurements the mercury thermometers are to some extent replaced by electronic thermome-

ters, but the mercury thermometers are still widely used in laboratories, e.g. for temperature measurements in synthesis baths.

A barrier for phasing out mercury thermometers in laboratories is that the use of mercury thermometers is prescribed by some standards used in the laboratories. Development of revised standards would encourage mercury substitution in the laboratory sector.

Barometers

Electronic barometers for automatic measurements of barometric pressure have in Denmark totally replaced mercury barometers for professional use in weather stations, airports, etc. Electronic barometers are also used for calibration of other barometers. The electronic barometers are as precise as the mercury barometers and have the advantage of automatic data logging. As mercury barometers have not been marketed in Denmark for many years, a price comparison has not been possible, but a study from the USA concludes that aneroid (mechanical liquid free) and electronic barometers are cost effective alternatives. Even though the electronic barometers may be more expensive than mercury thermometers, the lower price of mercury barometers would most probably not be a decisive property for the main part of the professional users. If available at significantly lower prices, the mercury barometers could perhaps be reintroduced for a few applications, where automatic reading is not requested.

Blood pressure measuring devices

The use of mercury sphygmomanometers for blood pressure measurements are not prohibited in Denmark. Mercury sphygmomanometers are still requested by some general medical practitioners and to a small extent by some hospital departments.

For use by the general public for measurements in the home, semi-automatic electronic devices has totally replaced mercury sphygmomanometers.

In hospitals, mercury sphygmomanometers have nearly 100% been replaced by aneroid (liquid-free) manual sphygmomanometers or electronic semi-automatic and automatic devices. The difference between the application patters in hospitals and by the general medical practitioners is partly that in hospitals use more advanced and expensive electronic equipment, partly that the hospitals have technical departments responsible for the maintenance of the equipment.

Mercury-free devices, validated with reference to the protocols of the British Hypertension Society or the International Society of Hypertension are available at approximately the same price as mercury sphygmomanometers.

The use of mercury-containing strain gauges, and alternatives to these devices, has not been investigated; reference is made to a recent Swedish study.

Other measuring devices

Mercury has previously, and to a small extent, been used in other types of measuring devices. The marketing of such devices in Denmark has been banned for some years. The alternatives marketed today have not been investigated in this project.

There are no current exemptions to the Danish ban.

Sammenfatning og konklusioner

Undersøgelsen viser at kviksølvholdige manometre, barometre og termometre, bortset fra visse anvendelser af termometre i laboratorier, er helt udfaset i Danmark og at der findes tilfredsstillende, omkostningseffektive alternativer til alle identificerede formål. Til blodtryksmåling efterspørges kviksølvholdige apparater stadig af nogle praktiserende læger og få hospitalsafdelinger. I de senere år er der sket en forbedring af de elektroniske og mekaniske kviksølvfrie blodtryksmålere, og en række forskellige apparater, som er godkendt efter anerkendte internationale protokoller, forhandles til priser svarende til prisen på kviksølvholdige blodtryksmålere. Det elektroniske udstyr har den ulempe at det for brugeren fungerer som en "sort boks", og at det ikke er umiddelbart nemt at se om det fungerer korrekt, hvilket indebærer at det skal kontrolleres oftere. På trods af disse ulemper fortrænger det elektroniske udstyr, som også har en række væsentlige fordele, manuelt udstyr i takt med at det elektroniske udstyr forbedres, og prisen på udstyret falder. Til avancerede målinger og kalibrering af andre termometre, manometre og barometre anvendes der i dag stort set kun elektronisk apparatur.

Baggrund

EU Kommissionen har den 24. februar 2006 udsendt et forslag til en ændring af Rådets direktiv 76/769/EØF med henblik på at begrænse markedsføringen af kviksølvholdige måleinstrumenter i EU. Med forslaget vil det generelle beskyttelsesniveau i EU på dette område forbedres. På visse punkter vil forslaget imidlertid kunne indebære at beskyttelsesniveauet i Danmark forringes i mindre grad, da de danske regler for nogle typer af måle- og kontroludstyr er mere restriktive end Kommissionens forslag.

I den følgende tabel er vist forskellen mellem de eksisterende danske regler og Kommissionens forslag.

Måleudstyr	Danske regler	Kommissionens forslag
Lægetermometre	Ikke forbud	Forbud
Andre termometre	Forbud undtagen til kalibrering og analyse-formål	Forbud mod salg til private
Blodtryksmålere	Ikke forbud	Forbud mod salg til private
Manometre	Forbud undtagen til kalibrering	Forbud mod salg til private
Barometre	Forbud undtagen til kalibrering	Forbud mod salg til private

Miljøstyrelsen har igangsat denne undersøgelse med henblik på at belyse, hvilke alternativer til kviksølvholdigt måleudstyr der i dag anvendes i Danmark, og i hvilken grad en ændring af reglerne vil kunne indebære at kviksølvholdigt udstyr kommer tilbage på det danske marked.

Undersøgelsen

Undersøgelsen bygger på oplysninger indhentet fra danske leverandører af

måleudstyr samt vurderinger fra danske eksperter i måling med det pågældende udstyr.

Historisk forbrug af kviksølv med måleudstyr

Forbruget af kviksølv med måleudstyr i Danmark er i perioden 1982/83 til 2000/01 faldet med en faktor hundrede (se tabel 1).

Årsagen til denne udvikling har dels været udviklingen af nye teknologier, især udviklingen af elektronisk udstyr til automatiske malinger, dels været miljøhensyn, som også har udmøntet sig i det eksisterende forbud mod markedsføring af kviksølvholdigt måleudstyr til de fleste ikke-medicinske anvendelser.

Tabel 0.1
Kviksølvforbrug i relation til brugen af måleudstyr i Danmark

Produktgruppe	Kviksølvforbrug (kg Hg/år)		
	1982/83	1992/93	2000/01
Lægetermometre	750	50	1.1
Andre termometre	1,300 - 1,800	100	15 - 20
Andet måleudstyr inklusive blodtryksmålere og kviksølv solgt til vedligeholdelse af måleudstyr	430 - 630	500	10 - 50
I alt	2,480 - 3,180	650	26.1 - 71.1

Andre termometre end lægetermometre

Markedsføring af kviksølvholdige andre termometre end lægetermometre er i dag forbudt i Danmark med undtagelse af termometre, som bruges til at kalibrere andre termometre eller bruges til laboratorieformål.

Alternativer, som kan erstatte kviksølvholdige termometre til alle anvendelser, er i dag tilgængelige på markedet (se tabel 2). Prisen på alternativer varierer betydeligt. Kviksølvfrie væske-i-glas termometre fås til omtrent samme pris som kviksølvtermometre, mens prisen for elektroniske termometre kan være op til 10 gange højere. På trods af den højere pris sælges de elektroniske termometre i stor udstrækning til alle typer anvendelser, idet fordelene ved at kunne lave automatiske målinger opvejer den højere pris.

Glastermometre med andre væsker kan erstatte kviksølvholdige glastermometre til de fleste anvendelser bortset fra målinger i temperaturområdet over 250°C samt målinger i laboratorier med en målenøjagtighed på mindre end 1 grad Celsius. For målinger ved temperaturer over 250°C i industrien anvendes typisk skivetermometre for manuel aflæsning eller elektroniske termometre for automatiske målinger.

Til målinger med høj nøjagtighed er kviksølv til en vis grad erstattet af elektroniske termometre, men kviksølvtermometre har stadig en udbredt anvendelse i laboratorier, fx for temperaturmåling i syntesebade.

En barriere for at udfase kviksølvtermometre til laboratorieformål er at brugen af kviksølvtermometre foreskrives i visse analysestandarder, som følges i laboratorierne.

Tabel 2
Markedsførte alternativer til kviksølvholdige termometre.

Anvendelsesområde / produkttype	Markedsførte alternativer	Pris på alternativer sammenlignet med kviksølvholdige termometre	Kommentar
Kviksølvholdige glastermometre til brug i på maskiner, motorer, kedler og lignende	Væske-i-glas termometre (op til 250°C)	~ samme pris	Har erstattet kviksølvtermometre til målinger op til 250°C
	Skivetermometre (op til 650°C)	~ 2-4 gange mere	Har erstattet kviksølvtermometre ved målinger over 250°C, fx i udstødning
	Elektroniske termometre	op til 10 gange mere	Vidt udbredt til automatiske målinger
Kviksølvholdige glastermometre til måling af temperatur i omgivende luft inkl. min/max målinger	Væske-i-glas termometre (op til 250°C)	~ samme pris	Bruges i en vis grad i termometre til at vise rumtemperatur
	Elektroniske termometre	op til 10 gange mere	Bruges til automatiske målinger og er standardudstyr i vejrstationer
Kviksølvholdige skivetermometre til fjernaflæsning af temperaturen i industrien og på skibe	Skivetermometre med kapillarer med andre væsker eller luftarter	~ 2-4 gange mere	Bruges til manuelle fjernaflæsninger
	Elektroniske termometre	op til 10 gange mere	Vidt udbredt til automatiske målinger
Kviksølvholdige glastermometre til brug i laboratorier	Væske-i-glas termometre (målinger med 1 grads nøjagtighed)	~ samme pris	Anvendes bredt til alle formål, hvor der ikke er behov for større end 1 grads målenøjagtighed
	Elektroniske termometre (med 0.1 grads nøjagtighed inden for et bredt temperaturinterval)	Op til 10 gange mere end ordinære Hg termometre ~ samme pris som certificerede Hg thermometre	Vidt udbredt til automatiske målinger og målinger med stor nøjagtighed

Manometre

Forud for det nuværende forbud udgjorde kviksølvmanometre af U-rørs typen kun nogle få procent af det danske marked for manometre. Kviksølvmanometre blev anvendt til målinger ved relativt lave tryk, især inden for VVS–branchen, fx i forbindelse med service på oliefyr, men kunne også bruges på enkelte maskiner.

Kviksølvmanometrene har uden større vanskelighed kunnet erstattes af andre typer manometre. Alternativerne er enten mekaniske fjedermanometre til manuel aflæsning eller elektroniske manometre med digital skærm og mulighed for dataopsamling. Til kalibrering af andet udstyr bruges også elektroniske manometre.

Ifølge de kontaktede leverandører fås de mekaniske fjedermanometre til priser, som varierer fra mindre end til omtrent samme pris som et kviksølvmanometer, mens prisen på de elektroniske manometre er 3-4 gange prisen på et kviksølvmanometer. De elektroniske har dog nogle væsentlige fortrin frem for de manuelle kviksølvmanometre, som opvejer den højere pris og er vidt udbredte. Ifølge leverandører er det meget usandsynligt at kviksølvmanometre vil blive genindført til nogen anvendelse i Danmark.

Barometre

Elektroniske barometre til automatisk måling af barometrisk tryk har i Danmark fuldstændig erstattet kviksølvbarometre til professionelt brug i vejrstation, lufthavne, m.m. Elektroniske barometre bruges også til kalibrering af andre barometre. De elektroniske barometre er lige så præcise som kviksølvbarometre og har den fordel at de kan udføre automatisk dataopsamling. Da kviksølvbarometre til professionelle formål ikke har været markedsført i Danmark i mange år, har det ikke været muligt at foretage en prissammenligning, men en undersøgelse fra USA konkluderer at aneroide barometre (mekaniske, væskefrie barometre) og elektroniske barometre er omkostningseffektive alternativer til kviksølvbarometre. Også selv om elektroniske barometre er dyrere end kviksølvbarometre, vil den lavere pris af kviksølvbarometre ikke være af afgørende betydning for flertallet af de professionelle brugere. Der vil muligvis være en begrænset efterspørgsel efter kviksølvbarometre til enkelte anvendelser, hvor der ikke er behov for automatiske målinger, hvis disse barometre kan leveres til væsentligt lavere priser end de automatiske.

Blodtryksmålingsudstyr

Det er i dag tilladt at bruge kviksølvholdigt udstyr til blodtryksmåling i Danmark. Blodtryksmålere med kviksølvmanometre (såkaldte sphygmomanometre) efterspørges stadig af nogle praktiserende læger og i en meget lille grad af visse hospitalsafdelinger.

Til blodtryksmåling i hjemmet har automatiske elektroniske blodtryksmålere helt erstattet kviksølvmanometre, og Dansk Hypertensionsselskab, som er den lægefaglige ekspertise på dette område, anbefaler i dag at der til hjemme- og døgnblodtryksmåling udelukkende anvendes automatiske apparater.

På hospitalerne er kviksølvmanometre næsten 100 % erstattet af elektronisk udstyr eller aneroide (dvs. mekaniske væskefrie) manuelle blodtryksmålere. Årsagen til de forskellige brugsmønstre hos hospitaler og de praktiserende læger er dels at der på hospitalerne anvendes mere avanceret og dyrere elektronisk udstyr, dels at hospitalerne har tekniske afdelinger som varetager vedligeholdelsen af udstyret.

Dansk Hypertensionsselskab angiver i deres seneste anbefaling at moderne aneroidmanometre er helt på højde med kviksølvmanometre, hvis de vedligeholdes regelmæssigt.

Forskellige typer af kviksølvfrie apparater, som er godkendt i henhold til testprotokoller udarbejdet af British Hypertension Society eller International Society of Hypertension kan fås til omtrent den samme pris som kviksølvmanometre.

Brugen af kviksølvholdige strækfølere (strain gauges), og alternativer til dette udstyr, er ikke blevet undersøgt, men læsere henvises til en ny svensk undersøgelse.

Andet måleudstyr

Kviksølv har tidligere i mindre grad været brugt i andre typer af måleudstyr. Markedsføring af sådant udstyr har i en årrække ikke været tilladt i Danmark til andet end kalibreringsformål, men det er ikke nærmere undersøgt, hvilke alternativer der i dag markedsføres.

Der er for øjeblikket ikke givet nogle dispensationer til brug af kviksølv til andet måleudstyr.

1 Introduction

The present study presents information on alternatives to mercury-containing non-fever thermometers, barometers, manometers and blood pressure measuring devices marketed for professional use in Denmark. The four groups of devices are selected because mercury until recently has been used or is still used in Denmark for some types of these devices. Besides the concerned applications, mercury may to a minor extent be used for other non-electrical or non-electronic measuring and control devices. Those devises are briefly described in Chapter 6.

1.1 Development of mercury consumption for measuring and control devices in Denmark

The development in the consumption of mercury for measuring devices during the period 1982/83 to 2000/01 is shown in table 1.1. During this period the total consumption of mercury for these application areas decreased nearly 100 times. The figures present the total mercury content of measuring devices sold in the years given in the table as well as mercury sold for maintenance of existing devices (relevant to "other measuring and control devices").

It is notable that the total consumption of non-fever thermometers in both 1982/83 and 1992/93 was about twice the consumption of fever thermometers. Similar results have been reported from the UK using figures from around 2000 (Floyd et al. 2002).

Table 1.1
Mercury consumption in relation to measuring devices in Denmark (Skårup et al. 2004)

Application area	Mercury consumption (kg Hg/year)		
	1982/83	1992/93	2000/01
Fever thermometers	750	50	1.1
Other thermometers	1,300 - 1,800	100	15 - 20
Other measuring and control devices including manometers, barometers, blood measuring devices and mercury for maintenance of existing devices	430 - 630	500	10 - 50
Total	2,480 - 3,180	650	26.1 - 71,1

1.2 Methodology

Thermometers, barometers and manometers
The marketing of mercury-containing thermometers (apart from fever thermometers and thermometers used in laboratories) manometers and barometers is banned in Denmark today. In order to describe the alternatives, which have substituted the formerly used mercury-containing devices, suppliers of relevant equipment have been contacted. Furthermore, research institutions using the most advanced devices for calibration of other devices, have been

contacted in order to obtain independent statements on the advantages and drawbacks of alternatives.

Blood pressure measuring devices

Mercury-containing blood pressure devices are to some extent used in the medical sector in Denmark today. Alternatives to the mercury-containing devices have recently been described in a Swedish study, which also describes the Swedish experience in replacing the mercury-containing devices (Kemi & Miljø Konsulenterne AB 2005). The major discussion concerning the use of alternatives in Denmark relates to the reliability and stability of the equipment in the actual use situation, in particular by the general medical practitioners. In order to supplement the information in the Swedish study with Danish experience, Danish suppliers of blood measuring devices have been contacted in order to investigate to what extent and by whom mercury-containing blood-pressure devices are purchased today. Furthermore, information on marketed alternatives to mercury-containing blood pressure measuring devices has been collected.

Examples of marketed equipment

In order to illustrate some alternatives to mercury-containing devices, some examples of devices marketed in Denmark are shown in this report. For each example a supplier, from which the information is obtained, is indicated. The equipment may quite likely also be supplied by other companies in Denmark.

2 Thermometers other than fever thermometers

2.1 Application of mercury-containing thermometers other than fever thermometers

Thermometers measure temperature.

Apart from fever thermometers, three types of mercury-containing thermometers were previously used in Denmark:

- Mercury-in-glass thermometers;
- Mechanical mercury thermometers with a dial for remote control;
- Contact thermometers (electric thermostats).

In Denmark, the use of thermometers other than fever thermometers is only allowed for calibration purposes and for laboratory use.

Mercury thermometers may in principle be used for all types of temperature measuring for manual reading in the temperature interval above the freezing point of mercury, -39°C.

The most common mercury thermometers consist of mercury encased in a thin glass tube that rises and falls with temperature. This thermometer was widely used in laboratories, as room thermometers and for temperature monitoring of machines, combustion processes and industrial processes. These types of thermometers are still allowed and marketed for use in laboratories. The mercury content was 10-20 g Hg/piece for large thermometers for boilers, whereas smaller thermometers contained 4-5 g Hg/piece (Hansen 1985). Thermometers used today in laboratories typically contain about 14 g Hg/piece corresponding to 1 ml mercury.

Another type, previously used for remote control of large engines or combustion processes, consists of a sensor on the machine, an up to 40 m long mercury filled capillary connecting the sensor and the control room and a gauge consisting of a bourdon coil with a pen or needle for reading the temperature (Rasmussen 1992). The mercury content ranged from about 5 to 200 g (Maag et al. 1996). These thermometers were mainly used for marine engine purposes and within the power sector.

Mercury-containing contact thermometers, in fact thermostats, were previously used for switching of a heating element in laboratories (Rasmussen 1992). When the mercury expanded in response to increased temperature, it established an electric contact between two terminals. The thermostats are electric equipment and not within the scope of the current study.

A thermometer with a U-shaped tube can be used for min/max thermometers indicating minimum and maximum temperature during a period of time. Mercury-containing min/max thermometers were previously part of the equipment of type of small weather stations called "English huts" [Danish:

engelsk hytte], but they have today been replaced by electronic thermometers (Dahl 2006).

For long transports in e.g. refrigerated containers, insurance companies demand continuous monitoring and verification of the temperature during the whole transport (Gustafsson 1997). According to a Swedish study, in the late 1990s a manually supervised instrument containing 190 g mercury dominated the market for marine transports. The use of such instruments has not been described in Danish studies, but it may have been used. Today, automatic devices without mercury, approved by the international insurance companies for supervision of refrigerated containers, are marketed.

Some standards, e.g. some German DIN standards, prescribe the use of mercury thermometers, which may be a hindrance for phasing out mercury thermometers for laboratory use. Development of revised standards would encourage mercury substitution in the laboratory sector.

Advantages and drawbacks of the mercury-containing equipment - Laboratory thermometers

Mercury thermometers used in laboratories are exempted from the Danish ban. The advantage of the mercury thermometers is that they are stable and easy to apply, and that it is immediately recognisable, when they are broken and do not function.

Compared with glass thermometers filled with other liquids, the mercury-containing thermometers are more precise and are the only suitable liquid thermometers for measurements at 0.1 degree resolution according to Andersen (2006). Thermometers tested and certified for accurate measurements at 0.1 degree resolution are marketed at prices of about ten times the price of ordinary mercury thermometers (Thoft 2006). The disadvantage of the mercury thermometers is that the thermometers easily brake and that the toxic mercury may be spread to the laboratory environment and surroundings at the breakage. Further, by heating of the thermometers, small bubbles may be formed in the mercury column resulting in a wrong reading of the temperature.

The available electronic thermometers are generally more accurate than mercury-containing thermometers, if properly calibrated. The laboratories accredited for calibration of thermometers typically use platinum resistance thermometers for calibrating other thermometers. According to Andersen (2006) from the thermometry laboratory of the Risø National Laboratory, an essential disadvantage of the electronic thermometers by normal laboratory use is that there is no visible indication, if the probe is damaged, e.g. after a drop of the thermometer onto the floor. Contrary to this, Nielsen (2006) from the national temperature reference laboratory of the Danish Technological Institute does not find any justification for the continued use of mercury thermometers in laboratories. The electronic thermometers are more accurate than the mercury-containing thermometers, but have to be calibrated more often. The electronic thermometers are typically calibrated every year, whereas mercury thermometers are typically calibrated every second year. When using the electronic thermometers it is necessary to check and recalibrate the thermometer, when it has been dropped. Nielsen (2006) finds this to be a relatively simple task compared to the clean up, when a mercury-containing thermometer is dropped.

- Thermometers for engines
For measurements in engines, the mercury-in-glass thermometers have the disadvantages that droplets may be introduced by the vibrations from the engine, if the thermometer is not held vertically (Petersen 2006). Further the long mercury-in-glass thermometers have the disadvantage that they can easily brake when handled. At this point the dial thermometers are of advantage.

Previous mercury consumption in Denmark
The consumption of mercury thermometers, other than fever thermometers, in 1982/83 was estimated at 1,300-1,800 kg Hg/year; of this roughly the half was used for industry thermometers (Hansen 1985). In 1992/93, the consumption had decreased to about 100 kg Hg/year, mainly used for production of marine diesel motors (Maag et al. 1996).

In 2001, non-fever mercury thermometers were only allowed for laboratory use. Skårup et al. (2004) estimate that a total of 1,000-1,500 mercury-containing laboratory thermometers were sold during 2001. By assuming that each thermometer contains about 15 g mercury, the total content of sold thermometers was estimated at 15-23 kg/year.

It has not, within the limits of the present study, been possible to obtain information allowing an updated quantification of the total sale of mercury-containing thermometers in Denmark. According to one of the main suppliers for the laboratory sector in Denmark, mercury-containing thermometers today account for about 10-15 % of the thermometers sold to the sector (Thoft 2006).

Applications where mercury may be reintroduced
Apart from the use in laboratories, industrial thermometers for temperatures above 250°C (typically measurements in exhaust gas) and thermometers for remote temperature reading in the marine and the power industry are the most obvious application areas, where mercury-containing thermometers may be reintroduced if they can be marketed at a significantly lower price than the mercury-free alternatives. According to the interviewed suppliers of thermometers and the main Danish manufacturer of marine diesel engines (Petersen 2006) it is, however, very unlikely that any company would reintroduce mercury in new machinery, because of the small price difference and because reintroduction of mercury would not be compatible with the companies' general environmental profile.

2.2 Alternatives for main application areas

A number of different types of non-mercury thermometers are marketed, among these:

- Liquid-in-glass thermometers;
- Dial thermometers;
- Electronic thermometers; (thermocouple and resistance thermometers);
- Infrared thermometers.

The thermocouple thermometers, platinum resistance thermometers and the infrared thermometers are all based on a thermoelectric principle and can via an analogue to digital converter be connected to a datalogger. These are sometimes jointly designated electronic thermometers or digital thermometers.

Liquid-in-glass thermometers

The liquid-in-glass thermometer is the most common replacement of the mercury thermometer at temperatures up to 250°C. Its appearance and structure is similar to mercury-in-glass; it consists of a cylindrical tube containing a liquid that expands and contracts with increasing and decreasing temperature. The liquids used in such glass thermometers include common organic liquids such as alcohol, kerosene and citrus-extract-based solvents that are dyed blue, red or green. The liquid-in-glass thermometers can immediately replace mercury room temperature thermometers.

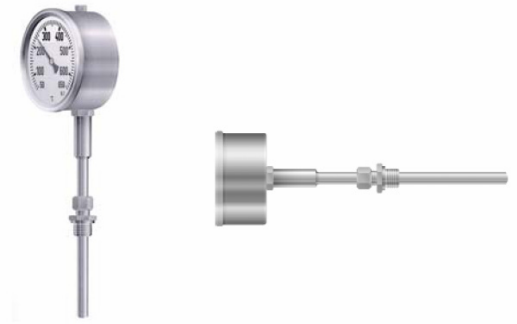
The coloured liquid thermometers for professional use are marketed by a number of suppliers in Denmark. The price is roughly the same as for mercury thermometers. According to Andersen (2006), the liquid-in-glass thermometers are not suitable for accurate measurements at 0.1 degree resolution, but the mercury-free thermometers are fully applicable for less accurate measurements. A disadvantage is that some of the liquid by heating may evaporate and condense as a colourless droplet in the top of the glass tube, which can only be observed under a magnifying glass (Andersen, 2006). The result may be that the thermometers read a half to one degree below the actual temperature.

Dial thermometers

A number of dial thermometers for manual reading are marketed for the use in the industry. Liquid or air filled thermometers consist of a liquid or air filled metal cylinder with a dial for manual reading. A bimetal dial thermometer senses and indicates temperature using a bimetal coil, which consists of two dissimilar metals bonded together. These materials have different coefficients of expansion and, when subjected to temperature change, rotate the coil.

The thermometers are available for measuring of temperatures in the range from about -70°C to 600°C. The dial thermometers have typically replaced mercury-in-glass thermometers for the temperature range above 250°C, e.g. for measuring the temperature of exhaust gases of diesel engines. The price for a dial thermometer for e.g. a diesel engine is reported to be about 2-4 times the price of a similar mercury thermometer (Petersen 2006; Sponholz 2006, Plesner 2006, Hau 2006). The price of e.g. a mercury-free dial thermometer for a diesel engine is about 400 DKK (53 Euro)/piece .

In the marine sector, insurance contracts in Denmark prescribe that the engines are equipped with thermometers which can work without external power (Petersen 2006). The manual thermometers often serve as backup for electric thermometers with automatic reading.



EXAMPLE:

Pförtner exhaust thermometer DS 100, type 45. Used for measuring the temperature of exhaust gas from diesel motors in the temperature range +50 to +650°C. (Pförtner Messtechnik GmbH & Co KG, germany)

Supplier: HNC Group, Korsør, Denmark

Source: http://www.hn-consult.dk/smartedit/upload/Datablade/Instrumentering/Termometre/03410%20udstødstermometer.pdf

EXAMPLE:

Tempress Bi-Metal thermometer type A87. Available for the temperature range -40 °C to +600 °C (Tempress A/S, Denmark)

Manufacturer and supplier: Tempress, Risskov, Denmark

Source: http://www.hn-consult.dk/smartedit/upload/Datablade/Instrumentering/Termometre/03510%20gasfyldt%20fjerntermometer.pdf

A number of dial thermometers for remote measurements of the temperature in industry, power plants and marine applications are available as alternatives to mechanical mercury thermometers for remote temperature reading. The thermometer probes are either filled with gases like nitrogen, argon or helium or liquids and attached to the dial by a capillary.

The price of the remote type thermometers are typically about 2-4 times the price of a similar mercury thermometer (Hau 2006).

EXAMPLE:

Nuova Fima remote gas-filled thermometer, type F84. Filled with nitrogen of helium (for low temperatures). Marketed for remote measurement of the temperature in the industry and power plants in the temperature range up to +600°C. (Nuova Fima, Italy)

Supplier: HNC Group, Korsør, Denmark

Source: http://www.hn-consult.dk/smartedit/upload/Datablade/Instrumentering/Termometre/03510%20gasfyldt%20fjerntermometer.pdf

Electronic thermometers

Electronic thermometers with a digital display and/or automatic data logging take up an increasing part of the thermometer market. The most common types are based on thermocouples, thermistors or resistance probes.

A thermocouple works because there is temperature-dependent voltage drop across dissimilar metals, which are placed in contact. In principle, a thermocouple can be made from almost any two metals. In practice, several thermocouple types have become standard. Thermocouples types designated K, J, T, N, S, R and B can be used for application in temperature ranges from -40°C to +1800°C (Senmantic 2006).

Thin-film resistance thermometers provide accuracy over a wide temperature range (from -200 to 850 °C). The principle of operation is to measure the resistance of a metal (typically platinum or nickel) element. The thermometers consist typically of either a metal coil or film surrounding a core of plastic, glass or ceramics. The most common type, designated PT100, is widely used for all types of application, where accurate automatic reading of the temperature is demanded.

Standard sensors are available from many manufacturers with various accuracy specifications and numerous data logging options to suit most applications. Some types of electronic thermometers for high accuracy and resolution combine the output from more probes.

Electronic thermometers are applied everywhere in the industry for automatic temperature measurements. For some applications, e.g. diesel engines for marine applications, the automatic measurements may be supplemented with mechanical thermometers for manual reading.

In weather stations in Denmark, PT100 thermometers with data logging are today standard equipment (Dahl 2006; Nehring 2006).

For laboratory use the electronic thermometers take up an increasing part of the market in Denmark (Thoft 2006). Thermometers with different probes are marketed for use in different media. Electronic thermometers for measurements at 0.1 decree resolution are available (Thoft 2006).

PT100 type thermometers are widely used for monitoring of the temperature of foodstuffs during transport (see example below). The thermometers are e.g. approved by Det Norske Veritas (DNV), Germanischer Lloyd (GL) and Lloyd's Register of Shipping (LRS). (http://www.kp-as.com/produktside.asp?item_id=82&action=fsp).

The electronic thermometers may substitute for mercury thermometers for some applications, but the mercury thermometers cannot substitute the other way around as they are not applicable for automatic measurements. If automatic measurements are not needed, the mechanical thermometers described above are cheaper alternatives and the options of choice.

The price of PT100 machine thermometers are in the order of magnitude of 10 times of a simple mercury-in-glass machine thermometer (Sponholz 2006). However, price comparisons are complicated by the fact that the electronic thermometers typically consist of two separate parts: a probe (sensor) and a datalogger. Several different probes may be used for the same data logger.

Electronic thermometers for use in laboratories are marketed at a price of about ten times the price of an ordinary mercury thermometers of approximately DKK 100 (Thoft 2006). The price of tested and certified mercury thermometers, however, is approximately DKK 1,200, similar to the price of the electronic thermometers.

EXAMPLE:

Handheld ECOM-HMF-PT100 for the temperature range -20°C to +400°C (Ecom Instruments GmbH, Germany)

Supplier: Vilstrup-teknik ApS, Silkeborg, Denmark

Source: http://www.vilstrup-teknik.dk/produkter/temperatur/ecom-hmf-pt100.php

EXAMPLE:

Aanderaa Air Temperature Sensor 3455 for weather stations. The sensor employs a 2000Ω film-type platinum resistor as the sensing element. Three ranges are available; –43°C to +48°C, –30°C to +60°C and –60°C to +30°C. (Aanderaa Instruments, Norway)

Supplier: ED Service-Center, Roskilde, Denmark

Source: http://www.aanderaa.no/render.asp?ID=140&segment=46&session=

EXAMPLE:

Resistance thermometer PT100 type: RT-RNP-USDA. Classified USDA sensor used for monitoring and control of the temperature of cold or frozen foodstuffs during transport from producer to consumer. Approved by "The Norwegian Veritas (DNV)", "Germanischer Lloyd (GL)" and "Lloyd's Register of Shipping (LRS).

Supplier: Kjærulf Pedersen A/S, Denmark

Source: http://www.kp-as.com/produktside.asp?item_id=303&action=fsp

Infrared thermometers

An infrared thermometer is a non-contact temperature measurement device. Infrared thermometers detect the infrared energy emitted by all materials and convert the energy factor into a temperature reading. Infrared thermometers allow users to measure temperature in applications where conventional sensors cannot be employed and are not immediately comparable with mercury-in-glass thermometers. Infrared thermometers have not been investigated further.

2.3 Summary

Alternatives for all applications of mercury-containing thermometers are marketed in Denmark. The price of alternatives ranges from approximately the same price (liquid-in-glass thermometers) to up to ten times the price of the mercury thermometer for some electronic thermometers. The price of the electronic thermometers is not directly comparable to mercury thermometers as the electronic thermometers have the advantage of automatic measurements and data logging

The liquid-in-glass thermometers can substitute for the mercury thermometers for most applications except for measurements above 250 °C or for measurements at less than 1 degree resolution. For high-temperature applications in the industry the mercury thermometers are typically replaced by dial thermometers for manual reading or electronic thermometers. For high resolution measurements the mercury thermometers are to some extent replaced by electronic thermometers, but the mercury thermometers are still widely used in laboratories, which is exempted from the current Danish ban.

A barrier for phasing out mercury thermometers in laboratories is that the use of mercury thermometers is prescribed by some standards used in the laboratories.

Table 2.1
Marketed alternatives for mercury-containing thermometers in Denmark

Application area / product type	Marketed alternatives	Price of alternatives compared to mercury technology	Comment
Mercury-in-glass thermometers for machines, engines, etc.	Liquid-in-glass thermometer (up to 250°C)	~ same price	
	Dial thermometers (up to 650 °C)	~ 2-4 times more	
	Electronic thermometers	up to 10 times more	Widely used for automatic measurements and data-logging
Mercury-in-glass thermometers for ambient air temperature measurements incl. min/max thermometers	Liquid-in-glass thermometer	~ same price	
	Electronic thermometers	up to 10 times more	Used for automatic measurements, datalogging and standard equipment of weather stations
Mercury dial thermometers for remote control in the industry	Dial thermometers	~ 2-4 times more	
	Electronic thermometers	up to 10 times more	Widely used for automatic measurements and data-logging
Mercury glass thermometers for laboratory use	Liquid-in-glass thermometer (at 1 degree resolution up to 250°C)	~ same price	
	Electronic thermometers (at 0.1 degree resolution at a wide temperature range)	Up to 10 times more ordinary Hg thermometers ~ same price as certified Hg thermometers	Widely used for automatic measurements and data-logging

3 Manometers

3.1 Application of mercury-containing manometers

Manometers measure the difference in gas pressure.

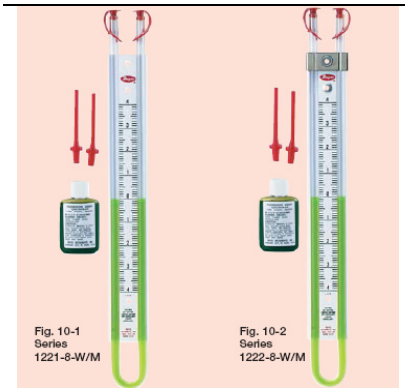
Mercury manometers are most often mercury-containing U-shaped glass or plastic tubes that have both or one end open. The difference in the levels of mercury in each side of the tube indicates the pressure of the gas being measured. Other designs are also available, e.g. slack tube manometers and well-type manometers.

In Denmark, sale of mercury manometers (except for sphygmomanometers discussed in chapter 6) are only allowed for calibration of other manometers.

U-tube manometers are used for measuring at relatively low pressures. The tubes may be filled with water, alcohol or mercury. U-tube manometers with water are today in Denmark used mainly within the heating and ventilation sector (HVAC sector), e.g. for difference pressure measurements when adjusting oil burners in single family houses (see illustration below).

The mercury-filled U- tubes were used for similar purposes in the mid-1990s when measuring at higher pressure (but still at relatively low pressures compared to the range of pressures found in the industry) (Ågård 2006). Besides, mercury manometers were used in the industry and in laboratories (Rasmussen 1992).

Laboratories calibrating manometers may still use mercury manometers as reference instruments, but the mercury-containing reference instruments are these years replaced by electronic instruments. For example, the last mercury reference instrument used by the reference laboratory of the Danish Technological Institute is replaced in June 2006 by electronic equipment (Thrane 2006).



EXAMPLE:

Dwyer Flex-Tube® U-Tube Manometers for HVAC applications (Dwyer Instruments Inc. U.S.A.)

Supplier: Hans Buck A/S, Albertslund, Denmark

Source: http://www.hansbuch.dk/files/datablad_cat_502.pdf

Advantages and drawbacks of the mercury-containing equipment
U-tube manometers have the advantage that they are relatively easy to apply, and it is relative easy to see whether they are working properly (DGC 1994). Droplets of other liquids, particles or bubbles in the tube may, however, result in errors.

The main drawback is that the mercury-containing manometer contain a hazardous substance in a quite fragile glass tube. Over pressuring a mercury manometer can result in the mercury being blown out of the tube contaminating the surroundings. By breakage the mercury may as well be released. Compared to electronic manometers, the mercury manometers are more difficult to read and more difficult to handle.

Previous mercury consumption in Denmark
According to Maag et al. (1996), in 1992/93 around 500 U-shaped manometers were sold each year in Denmark. The manometers were sold without liquid, and the suppler estimated that about 50 of the manometers was filled with mercury by the user, whereas the remainder was filled with other liquids, mainly water. The filled volume varies, but it was estimated that each manometer was filled with 70-140 g mercury corresponding to a total consumption in Denmark of 4-8 kg Hg/year. The most recent substance flow analysis from 2003 assesses the mercury consumption with manometers to be marginal, as the sale of new manometers was banned, and the mercury use with manometers was not assessed further (Skårup et al., 2004).

The number of manometers sold in 1992/93 (50 pieces) illustrates how marginal the use of mercury for manometers was. The total number of manometers sold in Denmark for industrial use is in the order of magnitude of 1000 times higher.

Applications for which mercury may be reintroduced
According to the contacted suppliers of manometers it is highly unlikely that mercury manometers would be reintroduced in Denmark for any use as they are vulnerable in use, and alternatives are available at the same or a lower price.

3.2 Alternatives for main application areas

Mercury-containing manometers have been replaced for all applications in Denmark

A number of different pressure-measuring instruments are marketed, among these:

- Bourdon tube manometers;
- Electronic manometers (or digital manometers);
- Pressure gauges with diaphragm elements.

As mentioned above, mercury manometers accounted for only about one per thousand of the manometers marketed in Denmark in the mid 1990's, and only manometers used for similar applications as the mercury manometers are mentioned below.

Bourdon tube manometers
The bourdon tube manometer is circular-shaped tube with an oval cross-

section. The pressure of the media acts on the inside of this tube. As the pressure increases, the tube will tend to uncoil, while a reduced pressure will cause the tube to coil more tightly. This motion is transferred through a link to a gear train connected to an indicating needle.

Bourdon tube manometers (see example) are today sold for applications, where U-tube manometers with mercury were previously used (Ågård 2006). The market price is about DKK 200 (27 Euro) which is probably lower than it would be for a mercury manometer (Ågård 2006). Plesner (2006) estimates that the price of alternatives to mercury manometers is probably about 1/3 of the price of the mercury manometer.

EXAMPLE:

Dwyer Magnehelic difference manometer with analogue reading for HVAC applications (Dwyer Instruments Inc., U.S.A.)

Supplier: Hans Buck A/S, Albertslund, Denmark

Source: http://www.hansbuch.dk/1866

Electronic (or digital) manometers

The electronic manometers measure the pressure by use of pressure transducers, e.g. piezoelectric pressure transducers or capacitance pressure transducers, which are connected via an analogue to digital converter to a display or datalogger.

The electronic manometers are widely used in the industry, as they can be used for automatic and remote control.

The price of electronic manometers is estimated to be about 3-4 times the price of a mercury manometer for similar pressure range (Plesner 2006), but the electronic manometers have the advantage of automatic measurements and can for this reason not be directly compared to the mercury manometers. According to Gallican et al. (2003), a digital manometer can also be more precise than the mercury manometer if properly calibrated.

Small hand-held manometers, that may serve a similar purpose as the mercury manometers, e.g. for applications within the heating and sanitation sector, are sold by many suppliers (see illustration below). The price of the hand-held manometer is approximately DKK 4000 (530 Euro), corresponding to about 4 times the expected price of a mercury U-tube manometer (Helbo 2006).

EXAMPLE:

Dwyer Handheld Digital Manometer model 475 series. (Dwyer Instruments Inc., U.S.A.)

Supplier: Hans Buck A/S, Albertslund, Denmark

Source: http://www.hansbuch.dk/files/DatabladDwyer-_cat_520.pdf

3.3 Summary

Previous to the Danish ban, mercury manometers accounted for only a few percentages of the manometer market. The mercury manometers were used for measuring relatively low pressures, e.g. in the heating and ventilation sector.

According to the contacted suppliers alternatives are available at similar or lower price than that of the mercury manometers, and it is highly unlikely that mercury manometers would be reintroduced for any application in Denmark.

Table 3.1
Marketed alternatives for mercury-containing thermometers in Denmark

Application area / product type	Marketed alternatives	Price of alternatives compared to mercury technology	Comment
Pressure measurement in the heating and ventilation sector	Bourdon tube manometers	Lower to similar price	
	Electronic manometers	3-4 times the price	The price of the electronic manometers is not comparable to mercury manometers as the electronic manometers have the advantage of automatic measurements and data logging

4 Barometers

4.1 Application of mercury-containing barometers

Barometers measure atmospheric pressure.

Barometers are used for a number of professional applications, among these in weather stations (e.g. the stations of the Danish Meteorological Institute or the Danish Forest and Nature Agency), airports and airfields, offshore installations (e.g. windmill parks) and on ships.

Mercury barometers contain elemental mercury in a thin glass column. The mercury rises and falls with changes in atmospheric pressure.

In Denmark, sale of mercury barometers is only allowed for calibration of other barometers. The Danish Meteorological Institute has today only one mercury barometer, "the institute reference", which is rarely used for certain calibration purposes today (Nehring 2006). Usually accurate electronic barometers based on the "vibrating cylinder transducer" principle are used for calibration purposes. Contacted suppliers of barometers for professional applications today solely use electronic barometers for calibration of other barometers (Dahl 2006; Røien 2006).

Previous mercury consumption in Denmark
The mercury consumption with barometers in Denmark has been considered marginal, and the undertaken substance flow analyses do not specifically quantify the consumption of mercury with barometers in Denmark. The total consumption of mercury with barometers in the UK around 2000 was estimated by Floyd et al. (2002) at 35 kg in 875 items. Assuming a similar per capita consumption in Denmark the consumption would have been around 3 kg.

Information sources from manometers of other countries report that barometers contain 40-1000 g Hg (Floyd et al. 2002) or 395-622 g (NEWMOA, 2006).

Applications for which mercury may be reintroduced
Apart from certain calibration purposes, no critical applications have been identified. The electronic devices are apparently superior to mercury-containing devices for all professional applications. According to a supplier small local airfields may still use their old mercury-containing equipment, as the automatic reading of the meter is not essential (Røien 2006). Small airfields seem to be one application area, where mercury-containing barometers might be reintroduced, if they could be supplied at a significantly lower price than electronic devices.

4.2 Alternatives for main application areas

A number of alternative barometers are marketed, among these:

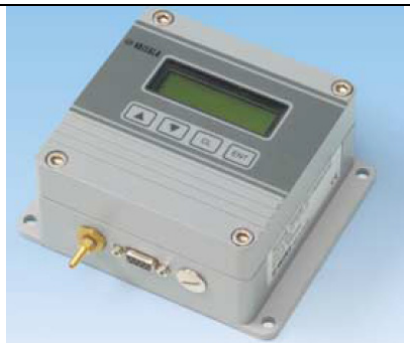
- Electronic barometers based on vibrating cylinder air pressure transducers;
- Electronic resistance or capacitance barometers;
- Aneroid mechanical barometers.

For professional use, electronic barometers for automatic data logging seem to represent the whole market today, whereas aneroid barometers may still be used for application in household.

Electronic barometer with vibrating cylinder air pressure transducers
A vibrating cylinder air pressure transducer is designed to measure absolute air pressure using the vibrating element principle, providing a frequency output from which pressure is computed. The pressure is applied to a thin-walled metal cylinder, which is set into motion at its natural frequency by electromagnetic drivers. As the air pressure inside the cylinder changes, the resonant frequency of the cylinder also changes.

Accurate barometers, e.g. for calibration of other barometers at the Danish Meteorological Institute, are based on the vibrating cylinder air pressure transducers principle (Nehring 2006).

Electronic resistance or capacitance barometers
A widely applied type of electronic barometers contain a sensor with electrical properties (resistance or capacitance) that changes, as the atmospheric pressure changes. These sensors are considered to be just as accurate as a traditional mercury barometer or an aneroid barometer (Gallican et al. 2003). Additional electronic circuitry converts the sensor output into a digital display or an automatic data logger. These barometers are today in Denmark applied in weather stations, ships, airports, etc. (Dahl 2006).



EXAMPLE:

Vaisala PTB220 Series Digital Barometer. Marketed as "barometric pressure standard, electronic alternative for a Hg barometer, weather stations, data buoys and ships, laser interferometers". Uses a silicon capacitive absolute pressure sensor. (Vaisala Oyj, Finland)

Supplier: ED Service-Center, Roskilde, Denmark

Source: http://www.edsc.dk/

Aneroid mechanical barometer
The mechanical aneroid barometer (aneroid = liquid-free) is more compact than the mercury barometer and consists of an evacuated metal diaphragm linked mechanically to an indicating needle. As atmospheric pressure increases or decreases, the diaphragm compresses or expands, causing the indicating needle to show the change in pressure. Aneroid barometers have been used for approximately 200 years and are considered just as accurate as the

traditional mercury barometer. (Gallican et al. 2003). No suppliers of aneroid barometers for professional use have been identified, and that barometer is probably not marketed for this application area in Denmark.

4.3 Summary

Electronic barometers for automatic data reading have totally replaced mercury barometers for professional use in Denmark. The electronic barometers are as precise as the mercury barometers and have the advantage of automatic data logging. The electronic barometers may be more expensive than mercury thermometers, but the lower price of mercury barometers would most probably not be a decisive property for the main part of the professional users.

Gallican et al. (2003) concludes that the aneroid and electronic barometers are cost effective in use and acceptable alternatives to the mercury barometer.

Table 4.1
Marketed alternatives for mercury-containing thermometers in Denmark

Application area / product type	Marketed alternatives	Price of alternatives compared to mercury technology	Comment
Weather stations, ships, offshore installations, etc.	Electronic resistance or capacitance barometers	Not assessed	Danish suppliers do not have an indication of the price of relevant mercury barometers
High-accuracy barometers, e.g. for calibration	Electronic barometer with vibrating cylinder air pressure transducers	Not assessed	Danish suppliers do not have an indication of the price of relevant mercury barometers

5 Blood pressure measuring devices

5.1 Application of mercury-containing blood pressure measuring devices

Two types of mercury-containing devices are used for measuring of blood pressure: mercury sphygmomanometers and mercury stain gauges.

Sphygmomanometers

A mercury sphygmomanometer (from Greek *"sphygmos"* for pulsation) includes a mercury manometer, an upper arm cuff, a hand inflation bulb with a pressure control valve and requires the use of a stethoscope to listen to the Korotkoff sounds. The method relies on the auscultatory technique, in which a clinician determines systolic and diastolic blood pressures (SBP and DBP) by listening (auscultate) for sounds that characterize different stages of blood flow during cuff deflation (so-called Korotkoff sounds). At certain points in the sound pattern, the clinician reads the pressure using the mercury column of the manometer.

Mercury sphygmomanometers have been used for more than 100 years and are still considered the "gold standard" of blood pressure measurements.

Strain gauges

Mercury strain gauges are used for blood flow and blood pressure measurements in body parts using a technique called strain gauge plethysmography (from the Greek *"plethysmos"* for increase: measuring how limbs change in size at different pressures). The mercury strain gauge consists of a fine rubber tube filled with mercury which is placed around the body part in which the blood pressure or blood flow is measured. The strain gauge technique registers changes in electric conductivity of the mercury in the tube, as the strain gauge is expanded by an increase of the circumference of the body part. The method is used for diagnosing certain kind of arteriosclerosis, a chronic disease in which thickening, hardening, and loss of elasticity of the arterial walls result in impaired blood circulation.

Mercury consumption in Denmark

The annual consumption of sphygmomanometers in Denmark was estimated at 300-500 pieces in 1994 (Maag et al. 1996). Each sphygmomanometer contained about 70 g mercury corresponding to an annual consumption of 20-35 kg Hg/year. For 2001, the annual consumption was estimated at 170-400 pieces corresponding to a mercury consumption of 12-28 kg Hg/year (Skårup et al. 2004). The main part of the sphygmomanometers was sold to general medical practitioners, whereas the mercury-containing equipment to a large extent had been replaced in the hospital sector (Skårup et al. 2004).

According to suppliers of equipment for blood pressure measurement in the hospital sector a few mercury-containing sphygmomanometers are still sold, mainly to cardiovascular departments (Bickley 2006, Hansen 2006a). For most applications within the sector, advanced electronic equipment for auto-

matic reading and data logging is applied. However, manual sphygmomanometers may e.g. still be used for routine measurements of patients with a weak or irregular pulse.

Some general medical practitioners still request mercury sphygmomanometers. Based on information from suppliers for this sector (Skibild 2006, Christensen 2006, Hansen 2006b), it is estimated that mercury sphygmomanometers account for 5-15% of the blood pressure measuring equipment sold for this sector. The total annual consumption in 2004 is estimated at the same level as in 2001, about 170-400 pieces, corresponding to 12-28 kg Hg/year . Within the last years the consumption has decreased, because some suppliers have ceased the marketing of mercury sphygmomanometers under the assumption that the marketing of the equipment was banned.

For private households, the market is totally dominated by electronic devices. A significant part of the electronic sphygmomanometers sold to general medical practitioners is actually lent to the patients for blood pressure monitoring in their homes.

The mercury consumption with strain gauges in Denmark has not been investigated. It is estimated by Kemi & Miljø Konsulenterne AB (2005) that no more than 200 strain gauge tubes are needed annually for the whole of Sweden. Assuming a similar per capita consumption this corresponds to about 100 strain gauges for Denmark.

Advantages and drawbacks of mercury sphygmomanometers

The advantages and drawbacks of mercury sphygmomanometers have been intensively discussed in the medical literature. Like for other measuring devices, the main advantage of the mercury sphygmomanometers is that mercury manometer is relatively easy to apply for people, who are trained in reading the meter, it is stable, and it is recognisable whether it functions adequately. They are still considered "gold standard" for blood pressure measurements.

The main drawback of the mercury sphygmomanometers, which is the main reason for their replacement in the hospital sector and the main reason for their continued phase out in other sectors, is that they are not suitable for automatic measurements. Further, the hazardous mercury may be spread to the surroundings by breakage of the manometer.

In spite of the accuracy of the manometer, blood pressure measurements with manual equipment are not necessarily reproducible, because many other factors influence the measurements. In the most recent guidelines on diagnostic blood pressure measurements, the Danish Hypertension Society (Dansk Hypertensionsselskab) conclude that it is now documented that both 24-hours measurements and blood pressure measurements at home are more reproducible and predict cardiovascular events more exactly than blood pressure measurements in the clinic (Bang et al. 2006). At the same time the guidelines recommend that only automatic devices are used for 24-hours measurements and blood pressure measurements at home. It is also concluded that aneroid manometers traditionally have been considered somewhat imprecise with a tendency to calibration drift. But today the modern devices, if maintained regularly, are as good as the mercury sphygmomanometers (Bang et al. 2006).

5.2 Alternatives for main application areas

Alternatives to mercury-containing sphygmomanometers on the market can roughly be divided into the following groups:

- Aneroid sphygmomanometers for manual reading;
- Semiautomatic devices for clinical use and home/self assessment;
- Automatic blood pressure devices for hospital use.

Alternatives to mercury strain gauges have not been investigated in this study, but reference is made to the description in the Swedish study undertaken by Kemi & Miljø Konsulenterne AB (2005).

Aneroid sphygmomanometers for manual reading
The manual aneroid sphygmomanometer works in a similar way as the mercury sphygmomanometer, but an aneroid (liquid free) gauge replaces the mercury manometer. The aneroid gauge may be desk mounted or attached to the hand bulb. The method relies on the ausculatory technique.

Aneroid sphygmomanometer has previously been considered less accurate than mercury sphygmomanometer in practical use. As quoted above, the Danish Hypertension Society concludes in their latest guidelines that the modern devices, if maintained regularly, are as good as the mercury sphygmomanometers (Bang et al. 2006).

A drawback has been that the manometers were susceptible to bumps. Different designs are available today, and recently the manufacturer Welch Allyn have introduced a new concept (DuraShock)for an aneroid sphygmomanometer that are more shock resistant than a conventional aneroid sphygmomanometer (Galligan et al. 2003). These types are marketed in Denmark with 5-10 years calibration guarantee by several suppliers (e.g. Kivex 2006) .

The example below shows a traditional type of aneroid mechanical sphygmomanometers that have been validated, meting the criteria of the BHS protocol of the British Hypertension Society (BHS 2006).

EXAMPLE:

Welch Allyn Maxi Stabil 3 aneroid sphygmomanometer. Meet the criteria of the BHS protocol of the British Hypertension Society (BHS 2006) (Manufacturer: Welch Allyn Medical Products, USA).

Supplier: Kivex, Hørsholm, Denmark

Source: http://www.kivex.dk/www-kivex/Files.nsf/Lookup/Blodtryksm%C3%A5ling_25-40/$file/Blodtryksm%C3%A5ling_25-40.pdf

A new type of aneroid sphygmomanometers marketed as alternative to mercury sphygmomanometers, e.g. as reference manometer, is shown in the example below. The device combines an electronic manometer with a dial for manual reading. The device carries out an auto calibration to zero each time it is switched on and meets the criteria of the International Protocol for blood pressure measuring devices in adults (BHS 2006). The sphygmomanometer is sold to general medical practitioners for use as reference instrument and clinical use.

EXAMPLE: Greenlight 300 electronic sphygmomanometer with manual reading, marketed as reference manometer. Using the auscultatory techniques and electronic manometer. Self calibrating when switched on. Meet the criteria of the International Protocol for blood pressure measuring devices in adult (BHS 2006) (Manufacturer: AC Cossor & Son (Surgical) Ltd., UK).

Supplier: Kivex, Hørsholm, Denmark

Source: http://www.kivex.dk/www-kivex/Files.nsf/Lookup/Blodtryksm%C3%A5ling_25-40/$file/Blodtryksm%C3%A5ling_25-40.pdf

The manual aneroid sphygmomanometers are widely sold in Denmark for applications by general medical practitioners and in hospitals. The prices for BHS validated devices range from about the same to twice the price of the mercury sphygmomanometers; the highest price for the electronic/manual reference sphygmomanometers. The price of a mercury sphygmomanometer is DKK 1,000 (excl. VAT) (133 Euro excl. VAT).

Semi-automatic electronic blood pressure devices

Semi-automatic electronic blood pressure devices have been developed extensively during the recent years, and a large number of different devices are marketed today. They typically use the oscillometric technique and include an electronic monitor with a pressure sensor, a digital display, an upper arm cuff and a hand bulb. By the oscillometric method, the blood pressure is not determined instantaneously, but is determined from the curves of the changes in the pressure and its oscillation. During cuff deflation, a pressure sensor transmits an electric signal representing the distension of the artery. Within the microprocessor, this signal is translated to systolic and diastolic blood pressure (SBP and DBP) using empirically derived algorithms. In addition to SBP and DBP, this type of device can display more comprehensive information about blood pressure patterns, which can be useful for diagnostics. An example is shown below.

The semiautomatic electronic devices are today standard for home/self assessment and are also widely used by the general medical practitioners. It has become increasingly common that the general practitioners buy the devices and lend them to the patients. The Danish Hypertension Society recommends solely use of the electronic devices for home/self assessment and 24-hour measurements (Bang et al. 2006).

The equipment meeting the criteria of the BHS protocol of the British Hypertension Society is available at approximately the same price as that of a mercury sphygmomanometer.

EXAMPLE:A&D UA 779 electronic sphygmomanometer using the oscillometric method. (Producer: A&D Company, Ltd., Japan). Marketed for professional use. Apply the oscillometric method.

Meeting the criteria of the BHS protocol of the British Hypertension Society (BHS 2006)

Supplier: Kivex, Hørsholm,, Denmark

Source: Source: http://www.kivex.dk/www-kivex/Files.nsf/Lookup/Blodtryksm%C3%A5ling_25-40/$file/Blodtryksm%C3%A5ling_25-40.pdf

Automatic devices for professional use in hospitals

For automatic measurements in hospitals, more advanced equipment, which often combines the measurements of blood pressure with monitoring of temperature, heart rate and blood oxygen level, are applied. The electronic box of the instrument typically includes multiple modules for measuring different vital signs. See example below.

The price of this equipment is typically in the order of magnitude of 10 times the price of a mercury sphygmomanometer (Hansen 2006a; Bickley 2006), but these advanced devices cannot be directly compared to the mercury sphygmomanometers, as they have much more features.

EXAMPLE: Welch Allyn blood measure device VSM 300 for automatic measurements of blood pressure with options for temperature and pulsoximetry.

Supplier: Kivex, Hørsholm,, Denmark

Source: Source: http://www.kivex.dk/www-kivex/Files.nsf/Lookup/Blodtryksm%C3%A5ling_25-40/$file/Blodtryksm%C3%A5ling_25-40.pdf

5.3 Summary

Examples of marketed alternatives with prices of the equipment in comparison to mercury devices are indicated in Table 4.1. The price of a mercury sphygmomanometer on the Danish market is about DKK 1,000 excl. VAT (133 Euro excl. VAT).

Aneroid manual mechanical sphygmomanometer and semiautomatic devices meeting the criteria of the BHS protocol of the British Hypertension Society (BHS 2006) are available at approximately the same price as mercury sphygmomanometers. These devices are widely sold to general medical practitioners, hospitals and the public.

Some general practitioners still request mercury sphygmomanometers. They are estimated to represent about 5-15% of the devices sold for this market segment. Mercury free aneroid manual electronic sphygmomanometer for use as reference instrument is marketed at about twice the price of the mercury devices.

Table 5.1
Marketed alternatives for mercury-containing thermometers in Denmark

Application area / product type	Marketed alternatives	Price of alternatives compared to mercury technology	Comment
Blood pressure measurements by general medical practitioners	Aneroid manual mechanical sphygmomanometer	~ same price	
	Semiautomatic electronic devices	~ same price	
Blood pressure measurements reference manometer for general medical practitioners	Aneroid manual electronic sphygmomanometer	~ 2 x the price	
Blood pressure measurements in the home	Semiautomatic electronic devices	~ same price	
Automatic blood pressure measurements in hospitals	Automatic blood pressure measuring devices for monitoring of blood pressure and other vital signs	~ 10 x the price	The equipment cannot be compared to mercury devices as it is much more advanced and typically monitor several vital signs

6 Other mercury-containing measuring devices

Apart from the devices described in this study, mercury may be used in a number of other measuring devices. The total mercury consumption in Denmark with these other measuring devices before the coming into force of the current ban is considered marginal, and no exemptions for applications on any of these devices have been granted by the Danish EPA. Alternatives to the mercury-containing devices have not been investigated in this study, but they are apparently available on the market.

Coulter counters

Rasmussen (1992) describes at the beginning of the 1990s that mercury may be present in coulter counters, used for automated counting and measuring the size of microscopic particles. They are widely used in the hospital sector. Mercury was in Denmark used in the manometers of the counters. From the U.S.A. it is reported that mercury may be present in a pressure gauge, on-off switch, timing count gauge, vacuum gauge and possibly other gauges, depending on the model (Sustainable Hospitals 2000).

Gas flow meters

Precision flow meters, used for calibration of gas flow meters for small flows, contained (and may still contain) mercury in a friction-less sealing (Rasmussen 1992). The precision flow meters were held by a few institutions calibrating equipment and in total about ten of these meters had been sold in Denmark (Rasmussen 1992).

Hygrometers

From the U.S.A. it is reported that mercury may be used in hygrometers (Gallican et al. 2003). No information on the use of mercury in hygrometers has been reported in Denmark, and it has probably not been used for many years (if ever). A hygrometer is an instrument used to measure the moisture content of air or any gas. The most common type of mercury-containing hygrometer is the "dry and wet bulb psychrometer." The psychrometer is best described as two mercury thermometers, one with a wetted base, and one with a dry base. The water from the wet base evaporates and absorbs heat causing the thermometer reading to drop (Gallican et al. 2003).

Hydrometers

From the U.S.A. it is reported that mercury may be used in hydrometers (Gallican et al. 2003). No information on the use of mercury in hydrometers has been reported in Denmark, and it has probably not been used for many years (if ever). A hydrometer is a device that measures the density or specific gravity of a liquid. Hydrometers are calibrated based upon the specific gravity of water at 60°C being 1,000. Liquids denser than water will have a higher specific gravity, while liquids less dense will have a lower specific gravity. The hydrometer is used for many applications.

Pyrometers

From the U.S.A. it is reported that mercury may be used in pyrometers (Gallican et al. 2003). No information on the use of mercury in hydrometers has

been reported in Denmark, and it has probably not been used for many years (if ever). Pyrometers are used to measure the temperature of extremely hot materials, and are used primarily for foundry applications. Infrared thermometers are today marketed for this application area.

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Annex 1 Contacted companies and institutions

All indicated companies and institutions are located in Denmark

Ametek Denmark, Allerød

Bie & Berntsen A/S, Rødovre

Brdr. Jørgensen Instruments A/S, Holte

Chiroform A/S, Viborg

Danish Meteorological Institute, Copenhagen

Danish Technological Institute, Århus

Dansk Diagnostika og Laboratorieforening (DADIF), København

ED Service-Center, Roskilde

Hans Buch A/S, Albertslund

HNC Group, Korsør

Kirudan A/S, Krøndby

Kivex A/S, Hørsholm

Kjærulf Pedersen A/S, Taastrup

Mærsk Andersen A/S, Randers

MAN B&W Diesel A/S, Frederikshavn

Nomeco A/S, København

NorDiaTech, Hedehusene

Plesner A/S, Birkerød

Risø National Laboratory, Roskilde

Seelen Læge- og Hospitalsartikler ApS, Holstebro

Senmatic A/S, Søndersøe

Tempress A/S, Århus