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Survey and Risk Assessment of Particle and Heavy Metal Emissions from Candles

Survey of chemical substances in consumer products No. 157

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Preface

The project ”Survey and Risk Assessment of Particle and Heavy Metal Emissions from Candles” was carried out from April 2015 – May 2016. The main objective was to investigate particle emissions from candles for candlesticks and to carry out a health assessment on the measured emissions.

The project was carried out by DHI, Danish Technological Institute (DTI) and the Danish Environmental Protection Agency (the Danish EPA). This report gives an overall outline of the work carried out in the project.

The steering group of the project consisted of the following participants:

- Kathe Tønning, Project Manager, DTI
- Peter Bøgh Pedersen, Senior Specialist, DTI
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Danish Technological Institute
Aarhus, May 2016

Based on incoming commnents in the public consultation of the original report, the Danish EPA decided in October 2016 to include an additional set of experiements of the emission form candles. The extra analyses measured the concenrtations of emitted particles from lit candles in a standard room. The Danish Technological Institute performed the experiments in December 2016 and the Dansih EPA implemented the results in the report from January – Marts 2017. The new measurements are described in section 6.2.2., and the results are secribed in section 6.4. Based on the extra results, the Danish EPA made changes in the report’s “Summary and Conclusion”, and in chapter 6, 7 and 8.

The Danish EPA
Copenhagen, Marts 2017

Summary and Conclusion

Introduction
This project forms part of the ”Chemicals Initiatives” that focuses on consumers’ exposure to hazardous chemicals. In that connection, it was chosen to focus on candles as a study shows that 39% of all Danes daily or almost daily burn candles at home. That results in an increased concentration of particles in the indoor environment and potential health hazardous effects.

The objective of this project was to get an impression of the extent of the particle emission coming from candles for candlesticks. To obtain a general overview, the concentration of the particles that are emitted from burning candles was measured with special focus on respirable and ultrafine particles. In addition, the amount of lead and nickel that is emitted from the candles, while they are burning, was quantified. Furthermore, the objective of the project was to clarify if a health related risk is involved when staying in a room where the investigated candles are burning.

The project was divided into three phases: survey and background knowledge, analysis of candles and health assessment.

Background knowledge
A candle consists of wax, a wick and possible dyes and additives. The wax is a solid substance at room temperature, but melts when heated. There are different types of wax, including stearin, paraffin, vegetable wax, animal wax and gel wax. The wick is usually made of cotton, but paper wicks are also used. In many cases, the wick is impregnated to ensure the correct stiffness of the wick, but also to protect the wick against corrosion by hot fuel. A soluble dye is used to dye the candles throughout, whereas pigments (solid, insoluble particles) normally are used to coat the outside of a candle ”surface dyeing” as they can influence the burn characteristics of the candle.

Legislation only states limits to the content of lead, which in Denmark must not exceed 100 ppm. In addition, the candle must meet the EU General Product Safety Directive (GPSD) that gives a generic definition of a safe product. Content of nickel is not specified more precisely for candles.

The Nordic Ecolabel is a voluntary, Nordic ecolabelling scheme that demands that candles must be made of 90% renewable materials; that a number of metals have not actively been added to the candle; and that the candle does not contain a number of organic compounds such as phthalates or halogenated solvents. The wick must not contain any metals at all.

Literature survey
In the course of the project, various searches were carried out in scientific literature databases and via search words on search machines to identify literature on candles. Several studies are available and most of them have an academic outlook. That means that a number of more or less advanced studies have been carried out on some candles. In the individual studies, the measurement set-ups vary depending on the objective of the study, just as the investigated parameters vary depending on the objective of the study. In general, it is difficult to compare the different literature studies due to these differences.

Some of the studies take a starting point in particle studies, and therefore advanced measurement equipment has been used to particularly look at particle sizes and particle masses. Other studies focus on health effects, which is why greater emphasis has been on the emission of organic compounds and PM2.5. Finally, other studies try to elucidate the effects of the content of, e.g., scents, whereas other studies mainly focus on the content of specific substances such as lead. In general, the various studies conclude that the particle emissions from candles constitute a substantial part of the particle pollution that people are exposed to indoors. The studies also show that wax type, wax purity, and a steady burn or burning in a draught are important issues with regard to the amount and type of emitted particles. Furthermore, several of the studies show that different organic compounds can be emitted from the burning candles in concentrations that, depending on the applied exposure scenario, can exceed the current limit and guideline values from, e.g., WHO, and that candles may contain lead and nickel. .

Overall, it can be concluded that a lot of literature is available, but it has been difficult to identify studies that could form the basis of this study.

Survey

In this project, a survey was carried out of the sale of white candles for candlesticks on the Danish market. In the period from 18 June to 19 August 2015, 36 retail chains, department stores and smaller specialty shops that sell candles were visited. 129 different candles distributed on 56 different brands were identified. Among them, 32 were white candles for candlesticks, and the rest were dyed candles. In the following, the burn time, price, wax type etc. are described for the 32 white candles:

- On the candle packaging, the burn time of each individual candle is stated to be between five and 14 hours.
- Unit price of the candles varies from DKK 1.20 to DKK 25.00/each.
- App. 1/3 of the candles were called stearin candles (wax type stearin), 1/3 *Unknown*, and the remaining 1/3 was made up of the wax type paraffin and different types of vegetable wax.
- Seven of the candles have the Nordic Ecolabel.
- App. half of the candles are made in Denmark, EU/Latvia, and for most of the other half of the candles, the country of origin is unknown; two of the candles were made in China.
- 17 of the packaged candles had additional consumer information, such as ”brænder med en klar og rolig flamme”, ”Lyset bliver ikke bøjet af varme omgivelser”, ”CO_2-neutralt råmateriale”, ”Danish quality control”, ”Godt miljøvalg”, ”Gennemfarvede – dyppede – selvslukkende”, ”Stearin, dyppet i farve i yderste lag for kulørtlys”, ”Håndlavede”, ”Lys med kanal så de ikke kan dryppe”, ”Hånddyppede”, ”Rodebutik”, ”Vægen er fremstillet af Ökotex certificeret bomuld” og ”I genbrugsbutikken kan du indlevere dine gamle stearinrester – hvorefter de smelter dem om til nye lys”.

Eight large Danish retail chains were contacted in the period from 26 March to 16 April 2015 in order to collect information about the sale of candles on the Danish market. Four retail chains (COOP, Dansk Supermarked, IKEA and Dagrofa) completed the forwarded questionnaire. From the collected information in the questionnaire survey it appeared that app. 90% of the around 45 million candles that are sold annually are white candles for candlesticks.

Health assessment

Burning candles influence the content of particles in the indoor environment. Therefore, this project made a preliminary health assessment to highlight potential health effects that may arise from exposure to particles created when burning candles.

In a study involving 56 Danish homes, average levels of ultrafine particles (particles <100 nm) were measured on between 1.5 x 10^3 particles/cm^3 and 2.5 x 10^5 particles/cm^3. In this study, candles were identified as a substantial source of the highest particle levels in homes with lit candles, and it was assessed that in average up to 60% of the particles originated from the burning of candles.

Upon review of the literature, no specific studies were found that highlighted the health impact of particles from burning candles. Data from the Danish CISBO project, however, indicate that residents living in private homes were slightly affected with respect to cardiovascular function and lung function when the level of ultrafine particles increases in private homes.

Other studies, where particles from candles were sampled and measured, have identified well-known toxic components, such as lead and nickel and polyaromatic hydrocarbons (PAH including benzo(a)pyrene).

The outdoor air particle content is more investigated than the particles indoor. On busy streets annual average particle levels of 15,000 – 18,000 ultrafine particles/cm^3 have been measured, and in very busy streets in Copenhagen, the particle levels during rush hour reach 30,000 – 40,000 particles/cm^3.

As the outdoor air particle content is known to have substantial adverse health effects, it raises concern whether or not particles from candles cause similar health effects.

Knowledge about the health significance of particles from candles (and particles in the indoor air in general) is very limited however, and for indoor air there is no health-based limit values for particulate matter as there is for outdoor air. Knowledge concerning the health effects of particles in outdoor air may provide clues to the potential effects of particulates in the indoor environment. However this will only be indications as particles in indoor air and outdoor air are expected to have different chemical compositions.

Particle emission measurements and chemical content analysis
129 different types of candles for candlesticks were identified in the survey, and out of them 32 were white candles for candlesticks. The 32 different white candles were chosen for particle emission measurement and chemical content analysis. White candles were chosen, as white candlestick candles amount to app. 90% of the entire sale of candlesticks on the Danish market.

In order to measure the particle emissions from the burning candles, the following methods were used:

- SMPS (Scanning Mobility Particle Sizer)
- DustTrak
- Sampling on filter for subsequent chemical analysis of emitted particles for content of lead and nickel

The concentration of particle emissions was measured close to the light source (20 cm above the flame) and in the room (1.5 m from the burning candle). The initial measurements of the burning candle were the measurements of source concentration. These measurements were carried out on 32 candles in the climate room while the temperature, air change and air humidity in the room were regulated. Next, on the basis of the source concentration measurements, 12 candles (5 paraffin candles and 7 stearin candles) were selected for the purposes of measuring room/exposure concentration of the particle emission. These measurements were carried out on the simultaneous burning of two candles of the same type in a climate room 20 m^3 in size with an air change of 0.5/hour.

Prior to the measurement it was stipulated that the candles must be burned under optimal conditions for combustion, and for this reason the burning candles was placed in a wire screen cylinder of a defined size and with defined air permeation, cf. DS/EN 15426.

With respect to both source concentration and room/exposure concentration, the study found that candles of the stearin wax type on average emit twice as many ultrafine particles as paraffin candles, with concentrations of respectively 19 million particles/cm^3 and 7.8 million particles/cm^3 measured at source and respectively 0.8 million particles/cm^3 and 0.46 million particles/cm^3 measured in the room, yet with significant variation and overlap between the two types of wax. Waxes of the type *Unknown* emit on average 9.8 million particles/cm^3 if measured at the source.

Similarly it was found that stearin and *Unknown* wax emit a larger mass of particulate matter than paraffin, albeit all in low concentrations (below 5 µg/m³).

The average particle diameter of the emitted particles measured in the room lies between 11 and 26 nm, which is greater than the diameter of the particles measured close to the source, which was between 7 and 18 nm. This result indicates that an agglomeration of particles occurs in the room, and it was observed that the emission from stearin candles agglomerated to larger particles than emission from paraffin candles. All of the discharged particles are very small, and have a rather constricted size interval when compared with *respirable particles*, which are particles less than 2.5 µm (2,500 nm) in size.

A chemical analysis was carried out on the 32 selected candles for content of lead and nickel in wax and wicks, respectively, and on particles sampled on a filter. Two candles from each of the 32 different candle types were analyses. Lead was found in the wax of at least one tested candle of four candle types, whereas nickel was found in the wax of two candle types. The chemical analyses showed that a large number of the wicks contained lead; that means, in 26 out of the 32 candles types lead was detected in at least one of the tested candles. A large variation was observed in the content of lead and nickel, also between candles from the same type of candlesticks.

A content of lead and nickel was also found in candles with the Nordic Ecolabel.

Exposure scenarios and risk assessment

The project aims to determine whether there is a health risk when staying in a room where candles similar to the tested candles are burning. Therefore, two exposure scenarios have been established that are both simple and realistic with regard to the use of candles (either of paraffin wax candles or stearin wax candles).

In the project, the following user scenarios were used to illustrate the use of candles for two different types of consumers:

Exposure scenario 1, regular user

This scenario represents the regular user of candles who on weekends (Friday, Saturday and Sunday) burns two candles, eight hours a day. Additionally, this scenario is split into two sub-scenarios, one involving optimal combustion and the other involving sooty combustion.

Exposure scenario 2, major user

This scenario represents the heavy user of candles who daily and all year around burns 4 candles, eight hours a day. This scenario can be regarded as “worst case”. Additionally, this scenario is split into two sub-scenarios, one involving optimal combustion and the other involving sooty combustion. In the sooty combustion sub-scenario it is assumed that two of the four candles are placed in a draughty spot, resulting in sooty combustion, since it is considered unrealistic that all candles would burn with an unsteady, sooting flame.

Sooting combustion has not been investigated in this project, and exposure scenarios involving sooting combustion are therefore evaluated on the basis of Pagels' et al. (2009), who investigated the emission from two candles (one white stearin candles and one blue mixed stearin and paraffin candle). Pagels et al. demonstrated major differences in the particle emission, depending on whether the candle burns with a steady non-sooting flame (optimal), or with a sooty and unsteady flame (sooting).

The particulate matter in the air (PM2.5) was calculated as average concentrations over a year for the specified user exposure scenarios, given that the potential adverse health effects are most significantly linked to the average exposure of PM2.5 over an extended period. In this project, levels between 0.0008 mg/m^3 for scenario 1 with optimal combustion of two paraffin candles (average for all paraffin candles) and 0.013 mg/m^3 for scenario 2 with optimal combustion of 4 stearin candles (stearin candles with the highest particle mass) were calculated. Based on Pagels' et al. study, levels between 0.006 mg/m^3 for optimal combustion of two mixed stearin/paraffin wax candles (scenario 1) and 0.282 mg/m^3 for four mixed stearin/paraffin wax candles with sooty burning of two of the candles (scenario 2) were calculated. Thus these calculations demonstrate a pronouncedly higher exposure during sooty burning of the candles.

With respect to the number of ultrafine particles in the air, the numberconcentration during burning in the various scenarios in this project was calculated as being between 916,000 particles/cm^3 (scenario 1 with paraffin candles) and 3,200,000 particles/cm^3 (scenario 2 with stearin candles). The study carried out by Pagels et al. calculated levels of 135,000 particles/cm^3 (scenario 1 with mixed stearin/paraffin wax candles) and 1,140,000 particles/cm^3 (scenario 2 with stearin candles). In both studies the highest calculated level was measured at optimal combustion of four stearin candles (scenario 2).

Risk assessment, particle mass concentration PM2.5
No threshold values are available for particle mass in indoor air. An indication of the health significance may be obtained by comparing the health-based limit values for outdoor air, This will only be an indication as particles in indoor air and outdoor air are expected to have different chemical compositions. If the calculated exposure levels for the particle mass concentration (PM2.5) are compared with the WHO recommended limit value for PM2.5 in outdoor air of 0.010 mg/m^3, we find that as regards the measurements in this project the threshold value is only exceeded in scenario 2 (optimal combustion of 4 candles simultaneously) for the stearin candle which had the highest discharged particle mass, whereas WHO's threshold value was exceeded in all scenarios (with the exception of scenario 1 with mixed stearin/paraffin candles) based upon Pagels' et al. measurements, which were also taken of sooty burning. In the scenario with the four mixed stearin/paraffin candles tested by Pagels et al., of which two are sooting the assessed annual PM2.5 level exceeded the WHO annual value of 0.010 mg/m^3 by up to 28 times.

It should be noted that the limit values for outdoor air cannot be directly transferred to indoor air and used for emission from candles, but by comparing the values this can give a first indication regarding potential adverse health effects caused by particle emissions from candles in the scenarios, in which the scenario with heavy use of candles and sooty burning causes high particle exposure. If this additional exposure to fine particles (PM2.5) – as in the outdoor air - can lead to increased occurrence/aggravation of cardiovascular diseases and respiratory disorders, needs to be further investigated, e.g. by looking into the chemical composition of the particles emitted by candles and comparing this with the composition of outdoor particles.
Risk assessment, concentration of number of particles
There are no health-based limit values regarding the number of ultrafine particles in the air, neither in outdoor air nor indoor air. That is because knowledge is still lacking in terms of the quantitative correlation between the concentration of particle numbers in the air and adverse health effects.

Based on recent data obtained in connection with the Danish CISBO project, it can be expected that exposure to elevated levels of particle numbers may affect the pulmonary and the cardiovascular system negatively.

It should be noted that the primary particles from the candles are very small (about 5-30 nm), and when deposited in the respiratory system, these particles will primarily be deposited in the most distal parts of the lung in the alveoli, from which the insoluble parts of the particle are only very slowly eliminated (months to years). The deposition and the possible accumulation of these particles in the alveoli might therefore induce adverse health effects.

On an average basis, the emission data obtained in this project indicate that stearin wax candles emit more particles than paraffin wax candles (and also a larger particle mass). However, it is very uncertain on that basis to conclude that stearin wax candles are more critical than paraffin wax candles, as that would require more knowledge of the composition of the particles and additional toxicity data. The burning circumstances are considered to be of greater significance than whether the candle is a stearin wax candle or a paraffin wax candle. A candle that burns with a sooty flame causes significantly increased PM2.5 levels and carbon levels in the air (much higher than the difference found between stearin and paraffin candles), and they are particular health concerns.

Risk assessment, lead and nickel

The measured levels of lead and nickel in the candles in this study are so low that exposure levels of concern are not to be expected, as the EU limit values for the substances (0.5 $\mu g/m^3$ for lead and 0.020 $\mu g/m^3$ for nickel in outdoor air) are not exceeded.

Based on the experiences from this project and as a general health recommendation, it can be recommended to make sure that the candles burn with a steady and non-sooting flame. This measure will reduce particle pollution significantly, as a sooting candle can emit a 30-70 times larger amount of carbon particles to the air compared to a non-sooting candle. Highest priority should therefore be given to selecting candles that burn with a steady and non-sooting flame.

Definition of Words

Abbreviation	Explanation
AAS	Atomic absorption spectroscopy
BTEX	Acronym for benzene, toluene, ethylbenzene and xylenes
CCT	Collision Cell Technology
CPC	Condensing Particle Counter
GC-MS	Gas chromatography – mass spectrometry
HS-PTR-MS	High sensitivity proton transfer reaction – mass spectrometer
ICP-AES	Inductively coupled plasma atomic emission spectroscopy
ICP-MS	Inductively coupled plasma mass spectrometry
ICP-OES	Inductively coupled plasma optical emission spectrometry
KED	Kinetic Energy Discrimination
LAS-X	Laser aerosol spectrometer
NOx	Overall designation of NO and NO2
POA	Primary organic aerosol
SOA	Secondary organic aerosol
SMPS	Scanning mobility particle sizer
PAH	Poly aromatic hydrocarbon
PCIS	Personal cascade impactor sampler
PM	Particulate matter
PTR-MS	Proton transfer reaction – mass spectrometer
TEOM	Tapered element oscillating microbalance
TGA	Thermogravimetric analysis
UV	Ultraviolet
VOC	Volatile organic compound
XAD2	Chemical adsorption material
XRF	X-Ray fluorescence

1. Introduction

This project forms part of the ”Chemicals Initiatives” that focuses on the consumers’ exposure to dangerous, chemical substances. In that connection it was chosen to focus on candles as a study shows that 39% of all Danes daily or almost daily burn candles at home. The study also shows that tea lights are the most popular candles among Danes (87% use tea lights) followed by square pillar candles (56%) and candles for candlesticks (53%). 41% of the Danes burn three to four candles at a time (YouGov investigation carried out by Bolius, November 2014).

The burning candles emit substances and particles that can result in pollution of the indoor environment. The Danish Environmental Protection Agency (the Danish EPA) has previously carried out a survey of candles. The survey detected small amounts of heavy metals in the candles, both in the wax and the wick, but the actual emission of heavy metals when candles are burning was not investigated. In addition, samples of the flue gas from burning candles were analysed more closely, and especially the particle emission was predominant (the Danish EPA, 2002).

1.1 Objective of the project

The objective of this project was to get an impression of the particle pollution that is emitted from candles for candlesticks (diameter 20-26 mm). The project illustrates the particle emission from burning candles, especially the respirable/ultrafine particles, and the amount of lead and nickel the candles can emit while burning. Furthermore, the project assesses if there is a health risk connected with staying in a room with the investigated burning candles.

1.2 Delimitation

This project does not comprise scented candles, birthday candles or ”seasonal candles” (Christmas candles, Easter candles or Danish calendar candles).

1.3 Method

The project was divided into three phases: survey and background knowledge, analysis of candles and a health assessment.

1.3.1 Background knowledge and survey

This phase was divided into the following sub-items:

Literature review

The literature search was carried out by searches on various search machines such as Google and Google Scholar, and databases on scientific literature (Science Direct, Springerlink) by using specific words related to the burning of candles. That i.a. included the search words ”particles”, ”emission”, ”candles”, ”measuring”, ”methods”, ”stearinlys”, ”partikler”, ”Svanemærket”, ”soot”, ”particulate”, ”nickel”, ”lead”, and ”indoor”. In Table 1 in *Literature Review*, a number of articles/studies on particle emission from candles and studies for content of, e.g., lead or nickel in the candles are mentioned.

Legislation and ecolabelling
Searches were carried out with different combinations of search words in Google, including: ”Levende lys lovgivning”, ”levende lys regulering”, ”svanemærket stearinlys”, ”levende lys partikler”, ”candles EU regulation”, ”candles legislation”. In addition, searches were carried out on the homepages of the Danish EPA or other relevant authorities, where search words such as ”levende lys” were used. The searches resulted in links to statutory orders, regulations, Danish EPA reports, popular science articles and reports concerning the establishment of criteria for the ecolabelling of candles. These sources have formed the basis of the contents in legislation and ecolabelling.

Survey
36 shops were visited, including nationwide retail chains (i.a., IKEA, Bilka, Bahne, Søstrene Grene, Lidl, Fakta, Kiwi, Føtex, Rema 1000, Tiger, Kvickly, Aldi, Plantorama, ILVA, Inspiration and Illums Bolighus), department stores (i.a., Salling and Magasin) and smaller specialty stores (i.a., Danmission, Bo Grønt, Sundhedskost, Alexandra Blomster, Ren Kost, Pariserhuset, and Det gamle apotek) in Aarhus and neighbourhood to find out which candles are sold. During the visits, the marketed candlestick candles were noted. Information available on the packaged products, regarding, e.g., country of origin, wax type and purity, was registered.

In the course of the survey, a questionnaire was prepared (see Appendix 1) and after telephone contact to relevant companies it was sent to the contact persons in the companies. The employees, who purchased or were responsible for the quality of the candles in the respective shops, were contacted.

Initial health assessment
The literature search and the literature review concerning emissions from candles also included a literature search on the health effects of particle emissions from candles. On the basis of the collected data, an assessment was made regarding the possible adverse health effects of the emitted particles and their different size fractions, and of the constituents of the particles. A decision will be made to whether or not health-related limit values can be set up regarding emission to be used in a later risk assessment in phase 3 of the project.

2. Background Knowledge

In the last 10-15 years, the interest in particle emission from candles has increased substantially. That is due to new and improved measuring techniques and increased focus on the possible health effects from inhaling ultrafine particles.

The following chapter describes the different types of candles and wax based on the newest literature in the field.

2.1 Candles and wax

A candle for a candlestick consists of two components: wax and a wick[1], respectively. At room temperature, the wax is a solid substance that melts when heated. Additives might be added to the wax, such as, e.g., dye, different types of scent or lacquer that looks like metal but is in fact an organic material. In general, a wax is made of esters, which is the chemical product of long chain fatty acids (16-36 carbon atoms) and long chain monovalent alcohols (24-36 carbon atoms). Wax is water-repellent and divided into four sub-groups: mineral, animal, vegetable and synthetic. Thise subgruops also cover fuels as vegetable or animal fat or fatty acids, but are in the following referred to as waxes.

The wax must be solid at room temperature and have a melting point that is high enough to avoid candles from bending in the sunlight (the Danish EPA, 2002). As candles typically burn indoors, it is also important that the wax does not contain too many impurities that can give problems with pollution (soot) during burning. The term wax is used in many connections. In this report, it is used as synonym for the inflammable material that surrounds the wick in the candle. The term wax is used for a complex substance that has not been specifically chemically defined, but that can be made of crude oil (synthetic wax or paraffin) or be of vegetable or animal origin. As a substance, wax is defined on the basis of physical-technical properties. Wax must have a melting point above 40ºC. At 40º C, it must be able to melt without decomposing, and it has to have a soft and workable surface. Wax normally melts at temperatures between 50 and 90ºC. Below, the various ingredients in candles are briefly described.

- Wax types
  - Stearin: Stearin for candles is a mixture of stearic acid (C_{18} fatty acid) and palmitic acid (C_{16} fatty acid), and it typically has a melting point around 60-62°C. Stearin gives the candle a white appearance.
  - Paraffin: Paraffin for candles is made of crude oil, typically C_{22}-C_{28} hydrocarbons, and is a mixture of paraffin, isoparaffin and cycloparaffin. The melting point is around 52-62°C, but can be lower, e.g., in tea lights as they often contain C_{18}. Candles are often covered with a paraffin layer with a melting point of app. 70-75°C to avoid candles from dripping. As paraffin is a mineral product (except Fisher Tropsch which is syntetic), it can contain aliphatic or aromatic hydrocarbon residue as well as other organic compounds. Paraffin is a broad term that also covers certain aliphatic compounds and certain alkanes.
  - Vegetable wax: Vegetable wax is an extract from suited types of wood – often different types of palm trees. (The plant -) wax is made in the epidermis of the plants and functions as an agent against dehydration and a defence mechanism against insect attacks[2]. The melting point varies according to wax type, but is around 83°C (e.g., for carnauba wax). “Vegetable waxes ar often based on palm, soya or rape oils.

[1] The Danish EPA, 2002

[2] http://www.denstoredanske.dk/It,_teknik_og_naturvidenskab/Kemi/Br%C3%A6ndselsmidler_-_kul,_t%C3%B8rv_og_gas_mv./voks

- Animal wax: for instance wax based on whales (spermaceti, no longer relevant in Denmark) or beeswax. Beeswax is a raw material that is used for expensive and decorative candles or candles for religious purposes. The Roman Catholic Church demands that their candles must contain at least 10% beeswax (Wolfmeier et al., 1986). Therefore, beeswax is mainly used in Southern Europe and America.
- Gel wax: Gel for candle making consists of crude oil and primarily amorphous hydrocarbons (soot is an example of an amorphous hydrocarbon) and can contain aliphatic or aromatic hydrocarbon residue and other organic compounds. Gel wax has no melting point.

- Wicks[3]
  - In principle, wicks are made of cotton and come in several different shapes and thicknesses depending on wax type, candle type and candle thickness. The wick dimension determines the melting, evaporation and burning of the candle, just as the wick moves liquid wax from the melting area to the burning area. Wicks can be impregnated to ensure stiffness, to prevent it from burning up completely when extinguishing the flame and to protect against corrosion by hot fuel. It was once common practice to use metal threads of, e.g., lead, tin or zinc in wicks, but today it is illegal to impregnate wicks with lead[4]for decades.

- Dyes[5]
  - Candles can be dyed in different ways. The large candle manufacturers annually develop new shades in order to adapt the candles to the current trend (colour range is often connected with a fragrance that has been added to a candle). Dyeing typically takes place by dyeing the candle throughout ("*dye*" added to the wax) or as a coating on the candle (with dye/pigment).
  - *Dyes* are available in liquid and solid form; they are added to the wax during the production process and are easy to handle by the manufacturers. As a starting point, *dyes* are inflammable, organic compounds and do not influence how the candle burns.
  - Pigments are small, solid particles that typically are used to colour surfaces (in the same way as paint). In principle, pigments are insoluble and will not fade in the course of time. As pigments are not inflammable, there is a risk that they will influence how the candle burns. Therefore, pigments are normally used to colour the surface of the candles and not to dye the candles throughout.
  - To a pronounced degree, private persons (and some smaller candle foundries) use the colour from chalk[6] to colour candles. The chalk is pregrinded and mixed in the wax before the foundry process.

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[3] The Danish EPA, 2002

[4] http://www.cancer.dk/forebyg/rens-luften/luftforurening/indendoers-luftforurening/stearinlys2/ - with reference to the Danish EPA, 2002

[5] http://candles.org/elements-of-a-candle/colorants/

[6] http://www.ourcandlemaking.com/giving-colors-to-your-candles/

2.2 Legislation and ecolabelling

In Denmark, it is illegal to import and sell products (including candles) that contain lead in concentrations exceeding 100 ppm (BEK 856, 2009 - especially enclosure 2, product category 2). Except for the ban on content of lead, there are no demands to which substances candles may contain. There is no statutory ban on nickel in candles. Only products that can be expected to be in direct and longer contact with the skin are covered by the EU Regulation in this field (EU No. 1907/2006, enclosure XVII, item 27).

In the absence of specific legislation and regulation, candles must as all other products in the EU live up to the EU General Product Safety Directive (GPSD) that gives a generic definition of a safe product. In Denmark, GPSD is carried out under the Product Safety Legislation. In addition, manufacturers are requested to follow the relevant standards from the European Committee for Standarisation (CEN). For candles, there is a standard for Product Safety Labels (EN 15494), a standard for Specification for Fire Safety (EN 15493) and a standard for Specification for Sooting Behaviour (EN 15426). The CEN standard for measuring soot specifies that candles should not have a soot index that exceeds 1.0/hour based on three standardised measurements, and that the soot index of each individual measurement should not exceed 2.0/hour. The soot index is a simple measuring method that is carried out by placing a glass plate at a well-defined distance above the flame. After a predefined period, the glass plate is removed and the attenuation of the light intensity (due to the deposited soot) is measured. It is not immediately possible to make a precise correlation between the soot index and the number of liberated particles.

The Nordic Ecolabel is a voluntary, Nordic ecolabelling scheme for various products, and it makes demands on the environment, health, quality and safety. There are requirements to the sooting behaviour of a candle with the Nordic Ecolabel (soot index of 0.3/hours in average for three samples of ordinary candles for candlesticks, and no single sample in excess of 0.6/hour). A content of i.a. aromatic and halogenated solvents, phthalates and active addition of a number of heavy metals such as lead, cadmium, mercury, chromium (CrVI), cobalt, antimony, zinc, copper, nickel and aluminium is forbidden (the wick must not contain metals). In order to be allowed to use the Nordic Ecolabel[7], 90% of the raw material of the product must be renewable, which limits the content of paraffin in candles (the paraffin must be fully refined (hydrogenated). The requirements have been defined by a wish to limit the use of petroleum products and not out of consideration for health. Therefore, candles with the Nordic Ecolabel mainly consist of renewable products such as animal stearin. Candles that fulfil all of the health requirements, but at the same time contain more than 10% paraffin, cannot be labelled with the Nordic Ecolabel.

In November 2015, the Nordic Ecolabel updated the Nordic Ecolabelling of candles. The proposal for updated requirements was sent to the nine largest manufacturers of candles in Denmark and the Danish EPA. The updated version contains intensified and differentiated requirements to the soot index depending on type of candle (tea lights, candles for candlesticks, square pillar candles or oil candles (recently added type of candle)).

[7] About candles with the Nordic Ecolabel – Version 2.0, 2014.

3. Literature Review

Recently, a lot of literature has been published about particle emission from candles and the possible content of, i.a., lead and nickel in candles. It has been difficult to compare the articles directly, as they have been published by various research groups, whose research has different intentions. As mentioned in Chapter 1.3, the articles were identified via a number of search words on various search machines (Google, Google Scholar) and databases of scientific literature (Science Direct, Springerlink).

The most substantial results and conclusions from selected scientific articles are outlined in Table 1. The articles were selected according to their relevance to this project. That means that they in general describe the emission of particles and gases from candles. In addition, articles that contain information about content of impurities, including metals, were chosen. In the following, the articles have been described in detail. The articles were chosen according to how well their content coincides with the objective of this study.

Table 1
Outline of identified literature with summary of the most important conclusions.

Article	Title	Conclusion
Marco Derudi et al. (2014)	Emission of air pollutants from burning candles with different composition in indoor environments.	Test of three (paraffin) candles in test chamber for chemical composition, VOC, PAH and particles (PM). Results: wax type and purity are of importance to emissions.
A. Manoukian et al. (2013)	Emission characteristics of air pollutants from incense and candle burning in indoor atmospheres.	Ventilated test room for testing joss sticks and candles (number not stated). VOC and particles measured with HS-PTR-MS and CPC, respectively. Found that particle and carcinogenic compound emissions could be compared to WHO limit values.
Melanie Bothe et al. (2010)	Organic aerosol formation in citronella candle plumes.	Test of scented candles (lemon, used as outdoor mosquito candles) in smog chamber for creation of SOA under the influence of ozone (number not stated). SMPS, PTRMS and UV used to determine considerable creation of SOA.
Joakim Pagels et al. (2009)	Chemical composition and mass emission factors of candle smoke particles.	Two representative conic candles were tested in a steel chamber for physical and chemical properties in the three phases; steady burning, sooty burning and smouldering (putting out). The first phase showed most organic salts, the next phase showed a large PM of soot agglomerates and the final phase mainly showed organic compounds.
Hsiao-Chi Chuang et al. (2011)	Combustion particles emitted during church services: Implications for human respiratory health.	The study showed that emitted PM from five types of candles (and two types of incense) during worship by far exceeds the EU guidelines regarding

Article	Title	Conclusion
		air quality.
Shirley J Wasson et al. (2002)	Lead in candle emissions.	Test of 100 candles for lead emissions. XRF, AAS, cyclone and LAS-X analyses. Lead content in wicks is a serious reason for lead pollution indoors.
Jerome O. Nriagu et al. (2000)	Emissions of lead and zinc from candles with metal-core wicks.	14 types of candles with metal impregnated wicks were tested for lead and zinc emissions and they showed high concentrations compared to the recommended amounts.
Gabriel Bekö (2013)	Ultra fine Particles: Exposure and Source Apportionment in 56 Danish Homes.	56 non-smoker homes were investigated for total amount of ultrafine particles over a period of 45 hours. In houses, where candles were burned, the candles were the source of more than half of the particle exposure.
Torben Eggert et al. (2002)	Kortlægning nr. 6, 2002: Indholdsstoffer i levende lys, der sælges i detailhandlen.	Six types of candles were chemically analysed and the smoke emissions were characterised for VOCs. It is concluded that the pollution from the candles depends on the type of candle as they all contained small amounts of i.a. lead and nickel.

In a study by Marco Derudi et al., a comprehensive study was carried out on three paraffin glass candles (candles made in a glass, ready for use) in a test chamber to investigate how the chemical composition influences the emission of VOC, PAH and particles. The following equipment was used: GC-MS, TGA and ICP-OES. O_2, NOx, SO_2, CO, CO_2 and temperature were monitored in a test chamber. In addition, gas samples for analysis were sampled on filters, XAD2 tubes and in gas bags, and PCIS sampled particles for mass determination. The study found that the emission of CO, SO_2, BTEX, PAH and PM depends more on the quality of the wax than on the additives added to the wax. Furthermore, essential oils added to the wax influence the PM emission, the particle size formation and the mechanism concerning particle creation. The conclusions are based on three tested candles.

Manoukian et al. investigated how the burning of candles and joss sticks influence the indoor environment. The particle concentration was measured with CPC and the creation of volatile organic compounds (VOCs) with HS-PTR-MS. The measurements were carried out continuously in a 32 m³ test room where it was possible to control the air change and to monitor the temperature and relative air humidity. The study found the emission of a wide range of VOCs and carcinogenic compounds such as benzene and formaldehyde, in concentrations close to the WHO limit values (WHO 2010: 17 µg/m³ and 100 µg/m³, respectively). Furthermore, an increased amount of particles was observed during the entire burning process.

A study by Melanie Bothe investigated the creation of secondary organic aerosol compounds (SOA) in candle smoke from scented candles. Lemon scented candles contain unsaturated essential oils that potentially produce SOA in reaction with ozone. Measurements were carried out in a test chamber with SMPS, PTR-MS and UV. It was found that significant amounts of unsaturated vapours were emitted resulting in the production of large amounts of SOA during exposure to ozone.

Joakim Pagels et al. carried out a study of two conical candles (pure stearin and a mixture of stearin and paraffin. The ratio of stearin and paraffin is not stated) to characterise the physical and chemical properties of the particle emissions in three sub-divided phases: steady burning, sooty burning and smouldering (when putting out). The objective was to investigate the physical and chemical effects of particles from burning candles in indoor air. The tests were carried out under controlled conditions in a 22 m^3 large stainless steel chamber with controlled temperature, relative humidity and air change. The analyses were carried out with SMPS, CPC, TEOM and cyclone and sampling on filters. As a result, they discovered that the main part of the particles during steady burning consist of easily soluble inorganic salt such as ammonium phosphate, alkali nitrate and sodium chloride. In connection with sooty burning rather high levels of soot were seen (elemental carbon/black carbon), whereas particles in smouldering condition were dominated by organic material.

In a study by Hsiao-Chi Chuang et al. from 2011, a characterisation was carried out of the particles generated during burning of candles and joss sticks during Mass. The objective was to illustrate the risk that is involved when candles and incense are burned during religious ceremonies. The studies showed that the concentrations were 91.6 µg/m^3 PM10 and 38.9 µg/m^3 PM2.5 for candles and incense, respectively. Both levels exceed the EU guidelines for air quality (25 µg/m^3 - please also refer to Table 6)[8,9]. In addition, the emission of particles from five types of candles and two types of incense were investigated in a smog chamber. The results showed that the emission of particles from joss sticks can constitute a risk of oxidative DNA adduction that is app. 30 times higher than for tobacco.

In 2001-2002, the American counterpart to the Danish EPA (US Environmental Protection Agency) (Shirley J. Wasson et al. (2002)), carried out a comprehensive study of 100 candles (measured in duplicate) where the emission of lead from candles with wicks containing lead was investigated (eight out of the 100. Out of the eight, seven were from the Far East). The objective was to illustrate if candlewicks contain lead. XRF, AAS, cyclone and LAS-X were used for the analyses. The lead wicks contained between 39-74% lead; the remaining was fabric or paper. In a testing chamber, average lead amounts of 100-1.700 µm/h were found. When converted into realistic indoor conditions that corresponds to concentrations that were higher than 1.5 µg/m^3 (EPA determined limit for lead concentration in the surrounding air), when burning one single candle or above 50 µg/m^3 (OSHA permissible exposure limit) when burning several candles at the same time.

In an older study from 2000, Jerome O. Nriagu et al. investigated the emission of lead from 14 different types of candles available in Michigan, USA that contained metal impregnated wicks. The objective of the study was to illustrate the problems related to candles with wicks that contained lead or zinc. They can potentially constitute a health risk in connection with inhalation, but also in connection with exposure from surfaces onto which the metals have been deposited after burning. The lead emissions amounted to 0.5-66 µg/h, the zinc emissions amounted to 1.2-125 µg/h. The measurements were carried out in a test chamber, where the metal vapours were trapped in an acid trap. The article concludes that burning four of these candles for two hours can result in metal levels that are potentially harmful to humans.

[8] http://www.euro.who.int/__data/assets/pdf_file/0005/74732/E71922.pdf

[9] http://ec.europa.eu/environment/air/quality/standards.htm

A comprehensive Danish study, carried out by Gabriel Bekö et al., investigated 56 Danish non-smoker homes in a period of ~45 hours in each house to find out, which particle concentration ordinary Danes are exposed to at home. The objective of the study was to clarify how Danes are exposed to particles in their own home, including how great a share of the particles originate from candles. The ultrafine particles (10-300 nm) were measured with a Nanotracer during the entire period, and developments were noted in a journal with exact hour and minute. In that way, it has been possible to conclude which sources are the largest contributors to exposure of nanoparticles. It was found that candles were responsible for more than half of the daily exposure to ultrafine particles in the home where candles were burned.

In 2002, a survey carried out by Torben Eggert et al. investigated which chemical compounds form part of candles, and which are emitted from candles when they burn. Six different types of candles were analysed. Chemical analyses showed that the candles contained rather small amounts of heavy metal, including lead and nickel. The largest concentrations were found in the wicks. In addition, the flue gas was analysed for VOCs, including PAH and aldehydes, and the sooting degree of the candles was assessed. The survey concludes that the degree of pollution depends on which type of candle is burning, and that the most important parameters such as wax type, candle dimensions and impregnation of the wicks do not appear on the consumer information.

3.1 Summing up and conclusion

The retrieved articles show that the particle emissions from candles in general constitute a considerable amount of the entire particle exposure, often in amounts that exceed the existing limit values or recommended amounts. The articles show that the way the candles are analysed and measured varies a lot from study to study, which makes it difficult unambiguously to compare values and give an overall conclusion regarding particle pollution from candles. A few articles show that some candles may contain wax and wicks that are impregnated with, e.g., lead or zinc, and that the lead emissions can constitute a potential health hazardous risk. In addition, an older Danish study of candles shows that wick and wax can contain small amounts of, i.a., lead and nickel.

4. Survey

4.1 Introduction to survey

During the survey of candles on the Danish market, a number of shops were visited from 18 June till 19 August 2015 in order to identify the selection of candles. That is outlined in chapter 4.2, and chapter 4.3 discusses the results of a questionnaire survey that was sent to some of the largest retail chains on the Danish market. The questionnaire survey was initiated to clarify how big the market for candles is, including how big a share candlestick candles constitute. The survey was carried out by contacting the largest actors on the market in order to obtain a true picture.

4.2 Shop visits

36 shops were visited, including nationwide retail chains, department stores, and smaller speciality stores (see chapter 1.3.1 for list). It is assessed that the sale of candles from the visited shops covers the main part of candles sold in Denmark. Eight of the visited shops did not sell candles, whereas the remaining 28 shops sold between 1-6 different candles for candlesticks. Some of them came in several shades. In all, 129 different candles for candlesticks[10] were identified, distributed on 56 different brands (one ”brand” could be marketed in two different shops and in this count it would be included both places). The extent and the degree of detail of the product information (wax type, burn time, country of origin and other marketing material) on the packaging of the candles differed a lot.

From the information found on the packaging it appears that the diameters of the candles for candlesticks vary from 20-24 mm and the height from 14-40 cm. The shop visits showed that 38 brands of candles for candlesticks were white, and 32 brands were coloured (giving a total of 70, whereas some of the candles were available in several colours, and therefore the final number of different candles was 129). The wax types varied and that appears in Figure 1. Besides, it was stated on 5 packages that the candles were unscented. The burn time of the 32 candles with available information varies between 5-14 hours. The unit price mainly varies from DKK 1.20 – DKK 5.00. In addition, some brands cost between DKK 7.30-DKK 25.00 each.

As appears from the following figure 1, in which the identified candlestick candles have been categorised according to wax type, *stearin* and *Unknown* each make up for app. 1/3 of the identified candles. The remaining 1/3 is made up of, i.a., paraffin and different types of vegetable wax.

[10] 129 candlestick candles were identified in the project. Candle 128 + 129 are missing, but the numbering goes from 1-131.

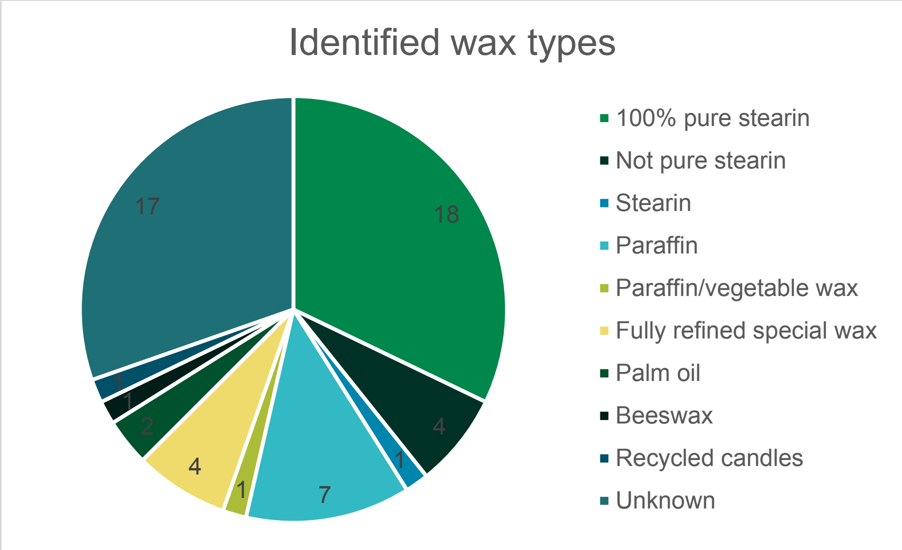

Figure 1
Identified wax types.

Seven of the identified candlestick brands were marked with the Nordic Ecolabel.

As appears in Figure 2, app. half (25) of the identified candles have no information regarding country of origin. The country of origin is stated on the packaging of 31 candlestick candles, and it is stated that two types of candles are produced in China, and the remaining candles are produced in Europe (seven in Denmark).

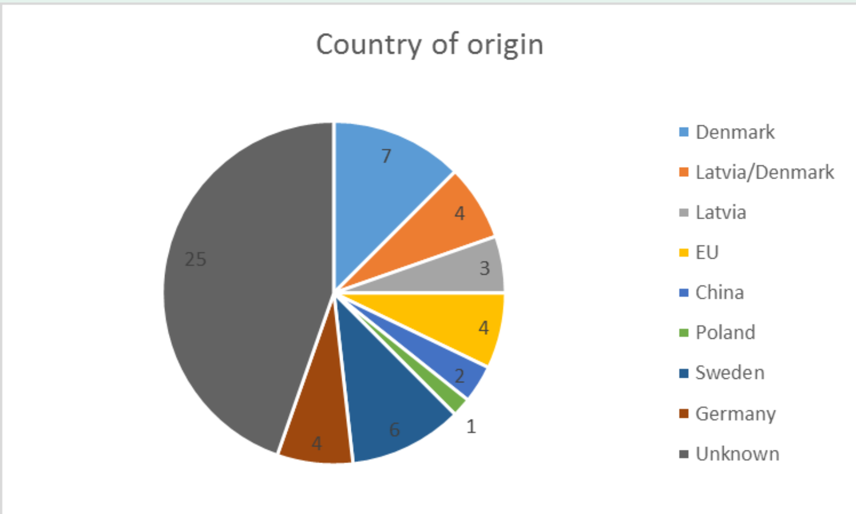

Figure 2
Distribution according to country of origin. One out of two packages from China was marked “Made in PRC” (People’s Republic of China).

17 of the packaged candles had additional customer information, such as ”brænder med en klar og rolig flamme”, ”Lyset bliver ikke bøjet af varme omgivelser”, ”CO_2-neutralt råmateriale”, ”Danish quality control”, ”Godt miljøvalg”, ”Gennemfarvede – dyppede – selvslukkende”, ”Stearin, dyppet i farve i yderste lag for kulørtlys”, ”Håndlavede”, ”Lys med kanal så de ikke kan dryppe”, ”Hånddyppede”, ”Rodebutik”, ”Vægen er fremstillet af Ökotex certificeret bomuld” og ”I genbrugsbutikken kan du indlevere dine gamle stearinrester – hvorefter de smelter dem om til nye lys”.

4.3 Questionnaire survey

In the period from 26 March to 16 April 2015, eight larger Danish retail chains were contacted to gather information on the sale of candles on the Danish market. Four retail chains (COOP, Dansk Supermarked, IKEA and Dagrofa) completed the forwarded questionnaire. Three of the completed questionnaires were very adequate, but one respondent only answered some of the questions. In the following, the answers from the questionnaire survey will be analysed and differences and coincidences will be emphasized.

The forwarded Danish questionnaire appears in Appendix 1.

4.3.1 Amounts

Candles for candlesticks are the second-most sold candles in Denmark only surpassed by tea lights. Pillar candles rank number three over sold candles in Denmark and the number of pillar candles comes close to the amount of candles for candlesticks. The share of candles for candlesticks is around 17-30% of the entire sale of candles in Denmark. Annually, the four retail chains sell app. 45 million candles for candlesticks and app. 90% are white candles. In the questionnaires, the amounts vary from 20,000 to 18 million candles/year.

On the basis of the received, completed questionnaires it is assessed that the survey covers app. 90% of the sold candles (for candlesticks) in Denmark. It has not been possible to get the figures confirmed by Statistics Denmark.

4.3.2 Manufacturers

The most frequently sold trademarks include: ASP, Änglemark, Bahne Engros, Diana, Ideas Daily (ID), IKEA (private label), Irma, No name and Windsor.

4.3.3 Company criterion for choice of candles

Different criteria create the basis for which brands the companies sell in their shops. In general, the quality of the candles is the decisive factor. The material choice is determined on behalf of many factors – straight from internal test procedures to European test standards for soot and burning tests, to the size of the candle, size of the packages, colour, price and season. More than half of the answers indicate that the price is decisive when choosing candles. Typically, the price is connected with quality, burn time and size.

About half of the retail chains use the Nordic Ecolabel as a quality parameter for which candles they carry, whereas the other half do not use the ecolabel as a selection criterion. Two answers indicate that Asian countries such as, e.g., China and Malaysia are rejected as countries of origin, usually because there have been quality-related problems. It is a decisive parameter for choice of candles that they are produced in Denmark or the EU (or in general close to where the candles are to be sold).

A larger retail chain carried out an internal study (carried out by researchers at DTU) of all candle brands sold in the chain. The study, i.a., revealed the particle emission from different candles in various user situations. The study was carried out to give the retail chain internal information about the emission of particles in user situations, so the retail chain can relate to the results if they are approached on that subject. The report is confidential and therefore the results have not been reported or referred to in the chapter called “Survey”.

4.3.4 Wax types and wick types

Either as direct knowledge or as knowledge from their wholesaler, three of the retail chains know which raw materials are used to make the candles. Candles for candlesticks are typically made of 100% stearin, paraffin, or often animal fat or vegetable fat. In some cases, the stearin has received the Nordic Ecolabel, whereas the paraffin in some cases has been RAL certified (German certification of raw materials). When the question regarding type was answered, the information is used as parameter for choice of candles. One retail chain informs that they only sell paraffin candles, whereas the other retail chains inform that most of the sold candlestick candles consist of *stearin* (between 80-100%), and the remaining candles are made of paraffin (0-20%). Few candles are made of other wax types, such as, e.g., vegetable wax.

Half of the answers showed that the shops have knowledge of the wick type. It is informed that the wicks consist of cotton that can be made in different ways or based on different techniques. In one case, the wicks had not been impregnated, whereas in another case they had in order to optimise the burning or extinguishing process. Actual impregnations, from which it appears what the impregnation agent was, have not been stated. The size, design and raw material of the candle all influence the choice of impregnation method.

4.3.5 Summary

The answers that were received in the survey show that candles for candlesticks are the second-most sold candles in Denmark. App. 90% are white candles for candlesticks, out of which app. 1/3 are made of *stearin*. The retail chains often use their knowledge of the candles' country of origin, quality, burn time, price etc. to choose, which types of candles they want to market. In half of the cases, certified labels such as the Nordic Ecolabel are used as selection criterion.

5. Health Assessment

This chapter focuses on the possible adverse health effects associated with exposure to the particles formed by burning candles. Particles can be described and measured in many ways, and therefore it is initially necessary to describe the measuring and characterisation of particles in the air in greater detail, before the health effects of the particles and the particle components are described. This chapter comprises the following sub-sections:

- Characterisation and measurements of particles
- Candles and their effect on the indoor environment and exposure to residents
- Harmful components from particles emitted from candles
- Health description of the components
- Health-based limit values for the components

5.1 Characterisation and measurement of particles

Particles in the air (Particulate Matter, PM) have traditionally been measured by leading the air through filters with different pore sizes and then determining the mass of the deposited particles on the filter. Depending on the pore size of the filter, the amount of particles in the air is expressed as either:

- Totally suspended particles (stated as the mass of TSP i.e. mg TSP/m^3 air)
- PM10 (mass for particles below 10 µm in diameter indicated as mg PM10/m^3 air)
- PM2.5 (mass for particles below 2.5 µm in diameter indicated as mg PM2.5/m^3 air)
- PM0.1 (mass for particles below 0.1 µm in diameter indicated as mg PM0.1/m^3 air)

Particles below 2.5 µm in diameter are also referred to as "fine particles", whereas particles below 0.1 µm in diameter are referred to as "ultrafine particles" or "nanoparticles". Since the mass of a particle is proportional to the third power of the diameter, that means that a particle of 1 µm weighs 1000 times as much as a particle of 0.1 µm, so the mass of the ultrafine particles only constitutes a negligible proportion of the mass, when particles are measured, e.g., as PM10 or PM2.5.

On the other hand, the *concentration of numbers* of airborne particles is dominated by ultrafine particles, especially where the air is dominated by combustion particles (e.g., from candles), as the soot particles from the combustion source are emitted as ultrafine particles. Optical measuring instruments or particle counter instruments can measure the concentration of number of ultrafine particles at various fractions of particle sizes in "number of particles/cm^3 air."

In order to obtain a measure of the presence of combustion particles in the air, this can be measured as soot content. Soot content is measured as *black carbon (BC)* by an optical method that measures the degree of darkening of a white filter on which the particles are sampled. Another way is to measure for pure carbon content *elemental carbon (EC)*, which is measured by a thermal-optical method.

When the ultrafine particles are emitted into the air, there is a rapid agglomeration of these tiny particles into larger particles, i.e., the lifetime of an ultrafine particle is relatively short. Therefore, in areas with high content of combustion particles, PM2.5 measurements can to a great extent be influenced by the content of these larger agglomerates of combustion particles.

Measurements of particles can be made by stationary measurements, which determine the amount of particles in a room or in the outdoor environment, e.g., along a busy road, and thus describe the particle content at a given location. If you are more interested in a person's exposure, the particle content can also be determined by portable measurement instruments, which can describe a person's total exposure over a day. Further, it may give you details concerning the personal exposure levels achieved while traveling in different micro-environments and in connection with various activities, such as cooking, driving, etc. (Danish EPA 2015).

5.2 Effect on indoor air and exposure

It is well-known that the burning of candles is very important for the content of particles in the indoor air (Danish EPA 2015).

Several studies have used portable measuring equipment for measuring ultrafine particles (particles smaller than 100 nm in diameter) and number of particles in the indoor air. In those studies, the particle levels have been measured at different locations, in different situations and during various indoor activities.

In a study involving 56 Danish homes, Bekö et al. (2013) reported an average level (geometric) of 22.3 x 10^3 particles/ cm^3 in the time period when residents did not sleep. During sleep and when nobody was at home, the average levels were below 6.1 x 10^3 particles/ cm^3. Great variation was found in the average 24 hour levels in the 56 homes, ranging from approximately 1.5 x 10^3 particles/ cm^3 to 2.5 x 10^5 particles/ cm^3 for the geometric mean values. In homes with lit candles, in average up to 60% of the measured particles originated from burning candles, and the home with the highest level, it was assessed that 97% of the particles originated from burning candles.

The average particle diameter was 76 nm (i.e., belonging to the fraction of ultrafine particles < 100 nm), while only 5% of the measured particles were above 120 nm.

An adult person who stays 24 hours in a home with high particle concentration will therefore with each inhalation (1500 cm^3) inhale 1500 cm^3 x 2.5 x 10^5 particles/cm^3 = 3.8 x 10^8 ultrafine particles, or during 24 hours with a daily inhalation volume of 20 m^3:

20 m^3 x 10^6 cm^3/m^3 x 2.5 x 10^5 particles/cm^3 = 5 x 10^{12} ultrafine particles per day

Similar results have been found in a recent Swedish study where the particle levels in 22 Swedish homes were measured over a 7-day period during winter. The daily mean levels of the 22 homes were in the range of 4 x 10^3 - 60 x 10^3 particles/ cm^3 (measured as particles below 300 µm). Candles had the greatest influence on the particle number concentration. In six homes, more than 60% of the particle levels was considered to be due to the burning of candles (for two homes about 80%), as highly variable particle levels from about 2 x 10^3 to ca. 2 x 10^6 particles/ cm^3 were measured during the burning of candles. Compared with soot measurements, it was found that there was good correlation (correlation coefficient of 0.64 ± 0.26) between soot levels and particle numbers in connection with the burning of candles (Isaxon et al., 2015).

There is very limited knowledge about the health related effect of indoor particles. On the other hand ultrafine particles and agglomerates of ultrafine particles from combustion sources in outdoor air (particles from e.g. traffic exhaust and wood combustion) are known to have comprehensive health effects. For the lack of any better, it may initially be relevant to compare the exposure to indoor particle levels from candle burning to outdoor levels (Danish EPA 2015). This will howver be an assumption, given the lack of published studies about the potential health effects of combustion particles indoor.

In the busiest streets, the average annual particle levels lie in the range of 15,000 – 18,000 ultrafine particles/ cm^3, which is more than 10 times below the levels measured in private homes with a high consumption of candles. In busy streets in Copenhagen, particle levels during peak time reach up to 30,000-40,000 particles/cm^3 (NERI 2011).

Despite inadequade information on health related effects of indoor particles, it seems relevant, solely on the basis of the heavy exposure to ultrafine particles from burning candles, to further consider and evaluate the possible health consequences of this.

Therefore, it is relevant to look for studies that address the health effects of particles formed when burning candles, and to examine the chemical composition and size distribution of the particles.

5.3 Identification of harmful components

Data from identified articles relevant to the health assessment has been collected and is shown in the following.

In a study by Derudi et al. (2014), where the emissions from three different candles in a test combustion chamber were analysed, it was especially the emission of particles and PAH that were assessed to be critical. From one of the candles, emissions of 239 µg particles (below 250 nm) and 33.2 µg particles (above 250 nm) per gram burned candle was measured. For the carcinogenic PAH and benzo(a)pyrene, the emission was 10.9 µg and 3.4 µg, respectively, per gram burned candle.

In a hypothetical exposure scenario, where the burning of two candles was assumed, a PM2.5 particle level of 98 µg/ m^3 and a benzo(a)pyrene level of 1.2 ng/ m^3 were calculated for a 30 m^3 room with an air exchange rate of 0.5 times/ hour. This was compared to a WHO reference value of 25 µg/m^3 for outdoor air, and an EU reference value for benzo(a)pyrene of 1 ng/ m^3 for outdoor air (see limit values in Table 5). However, the significance of exceeding these reference values was not discussed further in the study.

Manoukian et al. (2013) measured the particle number concentration in connection with the burning of a candle in a test room of 32.3 m^3. After one hour, 5 g of the candle was burned, the particle levels increased from 0.6 x 10^4 particles/ cm^3 to 22 x 10^4 particles/cm^3 (mean value of four tests). The emission rate of the candle was calculated to 2 x 10^{13} particles per hour.

Pagels et al. (2009) studied the particle emission from two candles: a stearin wax candle and a mixed stearin wax/paraffin wax candle. For the measurements four identical candles were placed in a testing room of 22 m^3. The candles were shielded from draught with metal cylinders to achieve an even burn with steady flames. Measurements under these circumstances were compared with measurements where the metal cylinders were removed and where the candles were subjected to ventilation in the room with a "wind speed" of up to 0.4 m/ s. This resulted in an unsteady flame with emission of visible soot. The measurement results showed that the particles from the non-sooty burning of a stearin wax candle mainly consisted of volatile substances, as more than 90% of the weight of sampled particles vaporised by heating to 200 °C. For the second candle made of a mixture of stearin wax and paraffin wax, the particle weight diminished only about 10% after heating.

The authors found that the particles from the stearin wax candle mainly consist of ammonium phosphate and diammonium hydrogen phosphate, which are substances that decomposes and evaporates when heated. The authors considered that the source of these salts was the wick, as a high phosphate content could be recovered in the wick, in which ammonium phosphate was probably added as a flame retardant.

Table 2 indicates the emission per hour for various particle measurements, and Tabel 3 indicates the emission per m^3 for the same parameters.

Table 2
Particle emission rates of particle constituents from two different types of candles (Pagels et al., 2009).

Candle type	PM2.5	Carbon	Organic material	Inorganic material	Particle number 16-1000 nm
	mg/h	mg/h	mg/h	mg/h	#/cm3
Stearin					
Optimal burn	2.4	0.14	0.04	2.9	1.14 E+06
Sooting burn	8.9	4.5	0.24	3.3	0.89 E+06
Stearin/paraffin					
Optimal burn	0.87	0.31	0.05	0.92	0.51 E+06
Sooting burn	25.3	19.0	1.3	1.1	0.27 E+06

Table 3
Particle levels* of particle constituents from two different types of candles after one hour burning of four candles in a testing room of 22 m3 (Pagels et al., 2009).

Candle type	PM**	Carbon	Organic material	Inorganic material	Particle number 16-1000 nm
	µg/m^3	µg/m^3	µg/m^3	µg/m^3	#/cm^3
Stearin					
Optimal burn	214	10	4	200	1.14 E+06
Sooting burn	603	340	18	245	0.89 E+06
Stearin/paraffin					
Optimal burn	86	20	4	64	0.51 E+06
Sooting burn	1604	1424	95	85	0.27 E+06

** The stated levels are according to the reading of bar charts indicated in Pagels et al., 2009.*
*** Not stated as PM2.5, but here stated as the sum of carbon, organic and inorganic material.*

It appears that the PM2.5 emission increases dramatically when the candle soots and thereby emits a high level of carbon particles. On the other hand, a slight decrease is seen in the number of particles when the candle soots, which is probably due to the fact that the small primary combustion particles quickly grow bigger due to agglomeration into larger and visible soot particles. Regarding the carbon level, it appears that sooting candles emit a 30-70 times larger amount of carbon particles than non-sooting candles.

During a sooting burn, an approximately 100 times higher concentration of particle numbers in the size of 270 nm ± 30 nm was observed than during optimal burning. However, the number concentration of particles below 100 nm (ultrafine particles) was somewhat lower during a sooting burn compared to an optimal burn. Due to this lower number of ultrafine particles during a sooting burn, an overall lower number of particles was found from sooting candles compared to optimal burn.

The authors concluded that the particles at optimal burn are probably less harmful to the health, as the content here is largely dominated by volatile substances and water-soluble salts.

Petry et al. (2014) performed burning of 11 types of paraffin wax scented candles in a 2.2 m^3 and a 26 m^3 test chamber, and in that connection measured the emission and the levels of a number of volatile substances, and PAHs, dioxins and particles. The fragrance content of the candles was about 6%. Particulate matter was the component that was emitted in the highest amount with an emission rate of up to 231 µg PM2.5/h measured in the large test chamber, where a chamber concentration of 9 µg PM2.5/m^3 was achieved. By scaling this result to a room comparable to the size of a small toilet, the authors assessed that a worst-case concentration of 90 µg/m^3 PM2.5 could be achieved. In the absence of limit values for particles in the indoor air, the authors compared the calculated PM2.5 level of 90 µg/m^3 with the WHO value (2005) and the EU value (2008) for PM2.5 in outdoor air of 10 µg/m^3 and 20 µg/m^3, respectively, and therefore concluded that PM2.5 must be considered as a critical component when burning candles. For the individual, volatile, harmful compounds, it was assessed that the emission of benzene was a critical component under the worst-case conditions.

In a Danish analysis of six selected candles, stearin wax as well as wicks were analysed for metal content (Danish EPA 2002). The highest levels of metals were measured in a blue candle:

Table 4
Content of metals in candles and maximum concentration in indoor air (EPA 2002).

Blue cobweb candle	Content in wax µg/g	Content in wick µg/g	Calculated conc. by burning µg/m3
Chrome	0.15	<0.2	0.15
Copper	2.2	1	2.2
Nickel	0.28	<0.3	0.28
Lead	0.11	0.9	0.11

Only two of the six candles contained chrome, while copper, nickel, lead and zinc were found in all six candles. Based on the burning rate of the candle (9.9 g per hour), the maximum concentrations of the metals in a room of 20 m^3 with an air exchange rate of 0.5 times per hour could be calculated after burning a candle and assuming 100% emission of the metal content into air (see Table 4, column 4). By comparing with the limit values in the work environment, nickel and lead were identified as the most critical substances.

5.3.1 Conclusion regarding critical components

In connection with the safety assessment of particles and metals emitted from burning candles, the data above indicate the following as most critical:

- PM2.5
- Particle number concentration
- PAH/benzo(a)pyrene
- Lead
- Nickel

It is important to keep in mind that the data indicate that the composition of the candles as such is of minor importance regarding possible health effects compared than the burning conditions, as sooty burning increases the mass emission of particulate matter significantly.

Emission of soot occurs primarily when the candle is in a draught with unsteady flame, if the wick does not create an even burn of the candle, when the wick is too long, by lack of ventilation (e.g., if the candle is in a glass), or if the candle has burned for a long time.

Soot can be avoided by ensuring that the candle burns down evenly, has a steady flame, is not placed in a draught, when the wick is not too long (less than 1 cm), and when the candle does not burn for too long (Bolias, 2014; BEC, 2014).

Below, existing limit values for the critical emission components are outlined, and a brief description of the most critical adverse health effects of components is given.

5.4 Hazard assessment of the components

5.4.1 Limit values for air

EU has not established any formal limit values for air pollutants in indoor air. In 2002-2004, the EU Commission conducted the so-called INDEX project where the objective was to identify the most relevant air pollutants in indoor air and assess them. The project resulted in detailed assessments of the substances formaldehyde, carbon monoxide, nitrogen dioxide, benzene and naphthalene (Koistinen et al., 2008).

In relation to ambient air, EU has determined a number of limit values for regulating pollutants in connection with Directive 2008/50/EC on ambient air quality and cleaner air for Europe. This Directive includes limit values and target values for 12 pollutants, including PM10, PM2.5, PAH/ benzo(a)pyrene, lead and nickel.

WHO has a long tradition of setting guideline values for air pollutants. The WHO Air Quality Guidelines for Europe 2000 have made recommendations for a total of 35 air pollutants (including particles, PAH/benzo(a)pyrene, lead and nickel). In 2006, the assessment and recommendation of particles was updated recommending guideline values for PM2.5 and PM10 (WHO, 2006).

Recently, WHO specifically made a number of recommendations for tolerable levels of air pollutants in indoor air. The recommendations include the substances formaldehyde, carbon monoxide, nitrogen dioxide, benzene, naphthalene, PAH, trichlorethylene, tetrachlorethylene, and radon (WHO, 2010).

In table 5, the current limit values/ guideline values for air pollutants relevant for this project are given.

Table 5
EU limit values and WHO's guideline values for selected air pollutants.

Pollutant	EU value Dir 2008/50/EC	WHO value
PM2.5	25 µg/m^3 (per 2010) 20 µg/m^3 (per 2020) Annual values*	10 µg/m^3 annual value 25 µg/m^3 24-hour value** (WHO, 2006)
Number of particles/ultrafine particles	-	-
Benzo(a)pyrene (indicator for PAH)	1 ng/m^3 Annual value	0.012 ng/m^3*** 0.12 ng/m^3*** 1.2 ng/m^3 *** (WHO 2010)
Lead	0.5 µg/m^3 Annual value	0.5 µg/m^3 Annual value (WHO, 2000)
Nickel	20 ng/m^3 Annual value	2.5 ng/m^3*** 25 ng/m^3*** 250 ng/m^3*** (WHO, 2000)

** The average level for the 24-hour mean values over a year.*
*** Measured average level over 24 hours.*
**** The three indicated levels correspond to increased lifetime risk of a cancer risk of 10^{-6}; 10^{-5} and 10^{-4}, respectively.*

Although, the above values are not specifically addressed to indoor air the values represent protective values for continuous exposure 24 hour per day and could be used for indoor air as well.

It should be noted that there are no limit values for the ultrafine particles and particle number concentration, as knowledge about the effects of these remains limited. This has recently been addressed in a very comprehensive overview report on ultrafine particles released by the Health Effects Institute (2013).

5.4.2 Particles

5.4.2.1 The fate of particles in the lungs

When describing the harmful effects of particles, it is important to keep in mind that different particle sizes are deposited in various parts of the respiratory system, and that the ultrafine particles are mainly deposited in the most distal parts of the lungs, the alveoli, see Figure 3 (Danish EPA, 2008).

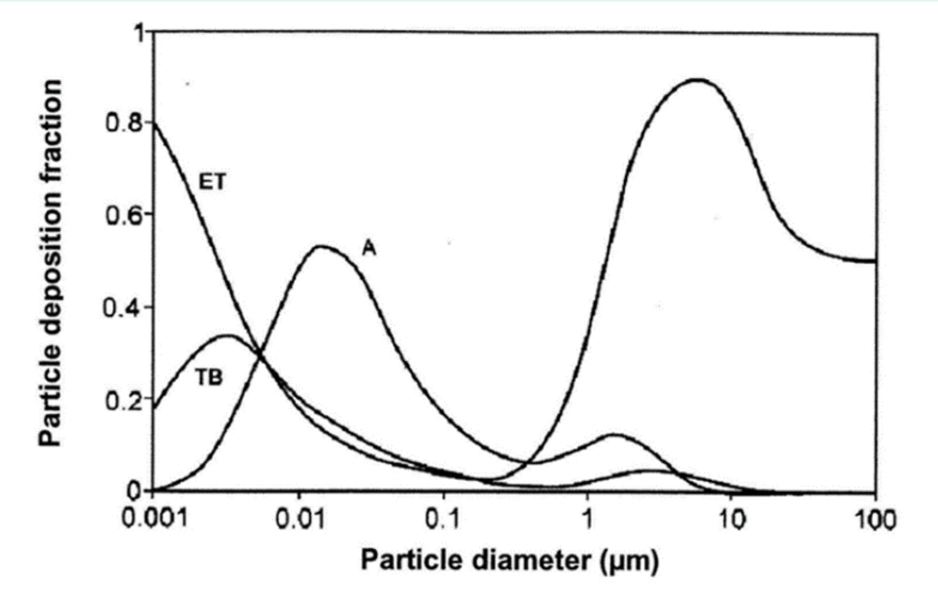

Figure 3
Particle size dependent deposition of particles in different sections of the airways. ET: extrathoracic airways (larynx and trachea); TB: lower part of trachea and bronchi; A: alveoli (Danish EPA, 2008).

Figure 3 shows that particles larger than 10 µm are mainly deposited in the upper airways, in the throat and in the upper part of the trachea (ET) where they subsequently are removed by coughing or swallowed with the saliva/ mucus. Particles below 10 µm may penetrate deeper into the trachea and bronchi (TB, tracheobronchial area) where they after deposit may be removed by the small cilia of the airways that brush them up into the throat from where they are subsequently swallowed. This occurs relatively quickly - within a few hours.

Smaller particles, typically less than 2.5 µm, and in particular the ultrafine particles (size of 0.01 µm to 0.1 µm) are deposited in the terminal airways, the alveoli (A) where a corresponding mechanism for elimination of the particles is not present, and where insoluble, persistent particles are only very slowly eliminated by decomposition or removal by macrophages, which are free cells that can absorb particles and transport them further up the airways. These ultrafine particles may also as a result of their small size, penetrate from the alveoli into the surrounding tissue of the lungs and through collection in the lymph liquid be transported into the bloodstream and from there distributed to the whole body. The smallest ultrafine particles of a few nm and less are deposited primarily in the bronchi and upper airways. Removal of insoluble particles from the alveoli is, however, a very slow process and may take years, and therefore prolonged inhalation of insoluble particles (e.g. metals and black carbon) will result in an accumulation of particles in the alveoli, which may lead to chronic and severe inflammatory conditions and cause a number of adverse effects (Danish EPA, 2008).

5.4.2.2 Harmful effects of particles

Knowledge of the harmful effects of particles primarily originates from data in relation to particles in the outdoor air, where numerous studies document the very significant effects on human health. Recently, the Danish report "Air pollution effects on health in Denmark", published by the Danish Centre for Environment and Energy, has provided a very comprehensive status (DCE, 2014).

Based on the current particle levels in outdoor air in Denmark, the report assesses the following health impact for the year 2011, Table 6:

Table 6
Health implications resulting from air pollution (primarily particles) in the outdoor air in Denmark (DCE, 2014).

Harmful effects	2011 Estimated number of cases
Chronic bronchitis	3,300
Days with reduced activity (sick days)	3,380,000
Hospital admissions for respiratory disorders	179
Hospital admissions for cerebro vascular disorders	416
Cases of heart failure	285
Lung cancer	506
Use of bronchodilators among children	88,800
Use of bronchodilators among adults	647,000
Episodes of cough among children	307,000
Episodes of cough among adults	666,000
Episodes with lower respiratory symptoms among children	215,000
Episodes with lower respiratory symptoms among adults	240,000
Number of premature deaths (due to short-term elevated levels)	142
Number of premature deaths (chronic exposure level)	3,330
Chronic life years lost (YOLL)	35,300
Deaths among infants	4

In the case of ambient air pollution, it is in general acknowledged that combustion related particles that may originate from traffic exhaust and wood combustion to a great extent contribute to the adverse health outcomes. Therefore, particles with a high content of combustion components have a significantly larger health impact compared to particles with a low content of combustion components – at least in case of outdoor particles.

The assessments of the health effects are based on the content of PM2.5 in the air (i.e., $\mu g/m^3$ of particles less than 2.5 µg in diameter), because this particle size has shown to be most closely related to the harmful effects, and thus contributes with the most robust does-response relationships.

In relation to the combustion fraction of the particles (which can be measured as elemental carbon (EC) or black carbon (BC)), indications have been found that the harmful effects of 1 µg/m^3 of these particles roughly corresponds to the effect of 10 µg/m^3 PM2.5 (DCE, 2014).

The particle number concentration in the air is dominated by the ultrafine particles largely made up of "fresh" combustion particles that have not yet coagulated and grown into larger particles. Although it is suspected that the ultrafine particles play an important role in the effects on health, there are not yet sufficient data to assess the health implications in relation to measured particle number concentrations (EPA, 2015).

However, a few studies have from relatively limited data attempted to highlight the importance of the combustion particles and the particle number concentration, Table 7 (EPA, 2015).

Table 7
Estimate regarding dose-response relationships for fine particles (PM2.5), combustion components (EC, BS) and ultrafine particles.

Effects	Increase in number of cases per year				Reference
Concentration parameter	PM2.5 (1 µg/m^3)	EC (1 µg/m^3)	BS* (1 µg/m^3)	Particle no. conc. (1000 ultrafine particles/cm^3)	
Number of premature deaths (chronic exposure)	0.6%	-	-	0.3%	Hoek et al., 2010
Number of premature deaths (chronic exposure)	0.7%		-	-	Janssen et al., 2011
Number of premature deaths (chronic exposure)	0.6%	6%	-	-	Hoek et al., 2013
Lung cancer	-	6%	-	-	Vermeulen et al., 2014
Number of premature deaths (acute exposure)	0.048%	-	0.068%	-	Janssen et al., 2011

** BS: Black Smoke is a measure of sooting degree/darkening of the collection filter.*

To indicate the perspective of these figures, it can be mentioned that an increase in the mortality rate of 6% for the Danish population, where about 55,000 people die each year, will correspond to approximately 3300 deaths per year.

5.4.2.3 Harmful effects of particles from candles and particles in the indoor air

Candles

In the literature search, no data were found regarding the health impact of inhalation of particles from candles over time. Regarding acute effects on the airways, Soppa et al. (2015) have conducted controlled laboratory studies in which a total of 45 healthy volunteers were exposed to particles derived from burning candles, toasting or sausage frying in a test chamber of 48 m^3. Two tests were conducted with two hours of burning either 20 or 40 Christmas tree candles. Four and 24 hours after the exposure, lung function examination was carried out by spirometry.

The lung function measurements (FEV1 and FVC and FEV1/ FVC and MEF25-75) were compared with various particle parameters measured in the chamber (PM10, PM2.5, PM1, total particle surface area, and particle number of the size fractions <100 nm, 0.5 µm-1 µm, 0.5-2.5 µm, and 0.5-10 µm).

None of the exposures, including the two candle exposures, showed any unambiguous effects on the lung function parameters. A few statistic models, however, found some correlation between the mass-based parameters and the influence of MEF25-75, a lung function parameter for influence of the fine airway branching.

Below, particle measurements related to the exposure are given. These measurements show that the number of particles above 0.5 µm is negligible compared to the large number of ultrafine particles, and that the weight of particles larger than 1 µm only represents a very small proportion of the total particle mass.

Table 8
Concentrations of particle number, particle surface area and particle mass after burning candles (Soppa et al., 2015).

	Particle number concentration (number/cm3)			
	<100 nm	**0.5-1 µm**	**0.5-2,5 µm**	**0.5-10 µm**
20 candles	191 x 104	6.2	9.7	9.9
40 candles	267 x 104	1.8	2.7	2.8
	Particle surface		**Particle mass (µg/m3)**	
	µm2/cm3	**PM1**	**PM2.5**	**PM10**
20 candles	2201	47.9	52.6	55.9
40 candles	3840	79.3	80.9	83.7

CISBO

A major Danish research project regarding indoor air quality and health in homes has been completed in 2016. The research project included five research institutions that worked together in “Center for Indeklima og Sundhed i Boliger” (Centre for Indoor Environment and Health in Homes) (CISBO). This research project, which among other things found that emission of particles from burning candles are of outmost importance for the particle number concentration in the indoor air (Bekö et al., 2013), also incorporates studies (see below) that illustrate the indoor climate in relation to health effects.

Karottki et al. (2014) studied 78 residents of the homes, which were subject to particle measurements made by Bekö et al. (2013), and which were heavily influenced by the use of candles (see chapter 3, Tabel 1). All of the residents were middle-aged, and their vascular and lung function were examined, and blood samples were taken and examined for various health related parameters. The results showed a statistically significant correlation between the particle levels (measured as particle number concentrations for particles sizes in the range of 10-300 nm) in the houses and reduced lung function, as well as higher serum levels of markers for diabetes and inflammation in the residents. As the highest particle levels in homes were closely linked to the burning of candles, the authors suggested that particles from candles could play an important role for these findings.

Another study by Karottki et al. (2013) assessed the effect of filtering the indoor air. In this study, 48 elderly people were studied, for whom during a 2-week period the air of their homes had been ventilated with and without a particle filter installed in a ventilation device. Examination of lung and vascular functions and of biomarkers in the blood did not show any differences in relation to the reduced particle levels (measured as PM2.5 and particle number concentrations for particles sizes in the range of 10-300 nm) obtained when the filter was mounted. However, in a sub-group of elderly people who did not receive any medication, improved vascular function (measured in the finger) in connection with the reduced levels of PM2.5 was found.

In the same group of elderly people, Karottki et al. (2015) also studied the correlation between the measurement results of the pulmonary and cardiovascular function studies and biomarkers in the blood with the particle levels in the outdoor air as well as in the indoor air. For each person who participated, the examinations were conducted seven times over a 4-week period, and then related to outdoor air levels of PM10, PM2.5 and particle number as well as indoor air levels of PM2.5 and particle number concentrations (particle diameter 10-300 nm). The study found significant correlation between the particle number in outdoor air and reduced vascular function (measured in the finger) and between outdoor air PM2.5 levels and inflammation markers in the blood. Indoor air PM2.5 level in the bedroom was correlated to increased level of markers for atherosclerosis in the blood, while indoor air levels of biological materials (e.g. microorganisms) in the dust were correlated to increased levels of markers for harmful effects on lung tissue.

In another CISBO project, Olsen et al. (2014) performed particle measurements (particle number concentration for particle sizes in the range of 10-300 nm and particle mass measured as PM2.5) in in 60 different non-smoker homes. The particle levels were measured in a 48 hour interval using partly stationary measuring devices and partly portable measuring devices. Immediately after the measuring period, the subjects were studied in terms of lung function and cardiovascular function as well as biological markers in the blood. The clearest correlation was observed for the personal exposure level for particle levels outside the home where increased levels were significantly correlated to influence of blood vessels (measured by decreased blood flow in the finger). An increasing number of ultrafine particles in the home showed a correlation to increased blood pressure and increased levels of inflammation markers in the blood. The latter effects were also seen for PM2.5 content of the indoor air.

However, these three CISBO studies did not specifically address the sources for the indoor particle exposure, including the contribution from candle emissions.

Overall, the CISBO studies indicate that particle levels in the home (both measured as particle number concentrations and particle mass) may have negative effects on lung function and the cardiovascular system.

The effects are comparable to the effects seen for outdoor air particle pollution. However, it should be noted that it may be difficult to separate the effects between indoor and outdoor particle pollution as outdoor air particles penetrate into the houses and thus also constitutes a significant part of the indoor exposure.

5.4.3 PM2.5 in indoor air

Although there is a significant amount of data documenting the adverse health effects of PM2.5 in outdoor air (see chapter 5.4.2), there is overall very limited data for assessing the effects of PM2.5 in indoor air, and especially from long term exposure.

In Norway, Folkehelseinstituttet recently conducted an assessment of particles in the indoor air to provide health based recommendations for the concentrations in the indoor air (Folkehelseinstituttet, 2014). As data for the assessment of particles in indoor air are very sparse, the recommendations regarding a limit value were instead based on the known dose-response relationships for particles in ambient air. Based on the WHO assessment (2006) of ambient air particles, the Norwegian Folkehelseinstituttet thus recommended a 24-hour value for particles measured as PM2.5 of 15 µg/m^3 and an annual value of 8 µg/m^3. It is however not clear from the assessment from Folkehelseinstituttet how exactly these values have been obtained, as they are somewhat below the WHO recommendations for outdoor air.

It should be mentioned in this connection that there is no lower limit for the health effects of PM2.5 in outdoor air, so the established limit values for PM2.5 cannot be interpreted as levels that completely protect against adverse health effects.

There are, however, major uncertainties by comparing indoor air content of PM2.5 with corresponding levels in outdoor air and relate this to the effects in outdoor air.

On the one hand, the comparison with the outdoor air particles may overestimate the effects of particles from candles, as outdoor air particles contain particularly harmful combustion components (e.g. from traffic exhaust and from wood combustion). Outdoor air particles must therefore be considered to be more complex and with a higher content of e.g. PAHs compared with particles from candles, which mainly consist of carbon and soluble salts.

On the other hand, considerable amounts of carbon particles may be released by a sooting burn of candles. A sooting burn may lead to a very high carbon content in the indoor air particles, which may constitute a significantly larger proportion of the particle mass compared to what can be seen in outdoor air. In outdoor air, combustion particles such as carbon usually constitute a minor part of the PM2.5 level.

5.4.4 Polyaromatic hydrocarbons, PAH

WHO (2010), in connection with the publication of the *air quality guidelines* for indoor air, assessed that PAHs, including benzo(a)pyrene, are extremely potent carcinogens having no lower threshold for the development of cancer.

WHO recommended to use the content of benzo(a)pyrene as a marker for the total carcinogenic effect in a mixture of PAHs, and assessed that a life-time exposure level of 1 ng benzo(a)pyrene/m^3 would correspond with an increased cancer risk of 8.7 x 10^{-5}. This means that exposure levels of 1.2, 0.12 and 0.012 ng benzo(a)pyrene/m^3 are considered to cause an increased lifetime risk of cancer of 1/10 000, 1/100 000 and 1/1 000 000, respectively.

EU has according to Directive 2004/107/ EC established a target value for the content of benzo(a)pyrene of 1 ng/m^3 in ambient air (as an annual average level).

5.4.5 Lead

EU has established a limit value for lead of 0.5 µg/m^3 in outdoor air as an annual average (2008/EC/ 50).

There are no known lower limits for the neurotoxic effects of lead in relation to development of foetuses and the central nervous system of children. Two EU expert committees, EFSA (2011) and the Risk Assessment Committee at the Chemicals Agency (ECHA, 2011), have assessed that the intake of 0.5 µg Pb/kg bw /d in children may cause a reduction in IQ of one point.

Children of 1-3 years of age with an average body weight of 11.6 kg inhale as a mean 7.0 m^3 air per day, which corresponds to 0.60 m^3/kg bw/d (NCM, 2011). With a content of lead in the air of 0.5 µg Pb/m^3 that results in an exposure of 0.3 µg Pb/kg bw/d, which is a daily dose corresponding to a loss of approximately 0.6 IQ points.

5.4.6 Nickel

For nickel, a target value of 20 ng/m^3 in ambient air has been established as an annual average level (EU-Directive 2004/107/EC).

Inhalation of nickel particles (both soluble and poorly soluble particles) causes chronic inflammation in the lungs, which may subsequently develop into cancer. The established target value protects against inflammatory responses in the lungs, and thus, at the same time reduces the cancer risk (European Commission, 2000).

The EU Scientific Committee for establishing limit values in the working environment, SCOEL, found that a practical threshold for nickel's carcinogenic effect would exist and that a limit value protecting against inflammatory diseases in the lungs would also protect against cancer. As a limit value in the working environment, SCOEL recommended a value of 0.005 mg/m^3 as an 8-hour average value (SCOEL, 2011).

5.4.7 Conclusion regarding reference values

In connection with assessment of particle emissions from candles, it seems appropriate to assess the obtained particle levels in indoor air with the following reference values:

Particles		
PM2.5	25 µg/m^3	(24-hour value)
	10 µg/m^3	(annual value)
PAH		
Benzo(a)pyrene	1 ng/m^3	(annual value)
Metals		
Lead	0.5 µg/m^3	(annual value)
Nickel	20 ng/m^3	(annual value)

For PM2.5, benzo(a)pyrene and lead, no lower exposure levels without harmful effects have been identified, and therefore the values represent tolerable risk levels rather than levels with no effect. For PM2.5, it was chosen to use the values recommended by WHO (2006) for ambient air. These values are lower than the EU requirements for ambient air, which have been set based on what is achievable in European cities, and thus reflecting pragmatic values rather than purely health based values.

However, it seems difficult to relate to the even lower values suggested by Folkehelseinstituttet in Norway, as the arguments for their choice of recommended PM2.5 values are very unclear.

For particle number concentrations in the indoor air, which primarily is a reflection of the content of ultrafine particles smaller than 100 nm, there are no recommended limit values. Here the assessment of acute effects can be compared with the effects seen for example in connection with data from the Danish CISBO studies.

For chronic exposure to ultrafine particles the data that could highlight the correlation with adverse health effects is insufficient. Table 8 gives estimates that show an excessive impact on mortality for a relatively small increase in the annual average value for particle number (1000 particles/cm^3) and an increase of inorganic carbon (EC) equivalent to 1 μg/m^3.

However, these figures must be considered as very uncertain, as increased mortality most consistently has been shown to be associated with PM2.5 levels rather than particle numbers and EC levels. On the other hand, data also indicates an increase in negative health impact with increasing proportions of combustion particles in the PM2.5 fraction.

6. Particle Emission Measurements and Chemical Content Analysis

6.1 Selection of candles for testing

As part of the survey 129 different candles for candlesticks were identified. Out of the 129 candles, all identified white candlestick candles, (a total of 32) were selected for particle emission measurements and chemical content analysis. The white candles for candlesticks were chosen, as they constitute app. 90% of the total sale of candles for candlesticks on the Danish market. When choosing candles, parameters such as country of origin, the Nordic Ecolabel, information about the wick type, different prices and wax types were investigated. Dyed candles were not investigated in this study – mainly because the share of dyed candles for candlesticks only amounts to app. 10% of the total amount of candles for candlesticks that are sold in Denmark, and also because an in-depth survey of whether dye (additives etc.) influences the particle emissions would be beyond the framework of this project.

Table 9 shows the selected candles for candlesticks that were analysed in the following tests.

Table 9
Information from manufacturers about the 32 selected, white candles for candlesticks tested for particle emission and content analysis.

Candle No.	Wax Type	Information about Wick	Country of Origin	The Nordic Ecolabel
5	Stearin	No	Sweden	No
6	Stearin	No	Sweden	No
12	Paraffin	No	Unknown	No
19	Stearin	No	Latvia/Denmark	Yes
21	Stearin	No	Unknown	No
40	Unknown or mixed	No	EU	No
44	Stearin	No	Denmark	Yes
45	Stearin	No	Unknown	No
46	Paraffin	No	Unknown	No
59	Paraffin	No	Latvia	No
69	Stearin	No	Unknown	Yes
70	Stearin	No	Latvia	Yes
71	Stearin	No	Latvia	No
72	Stearin	No	EU	No
74	Unknown or mixed	No	Unknown	No
76	Unknown or mixed	No	Unknown	No
82	Unknown or mixed	No	Unknown	No
87	Unknown or mixed	No	Unknown	No
94	Paraffin	No	Unknown	No

Candle No.	Wax Type	Information about Wick	Country of Origin	The Nordic Ecolabel
100	Stearin	No	Unknown	No
101	Stearin	No	Unknown	No
102	Stearin	No	Unknown	No
103	Stearin	No	Unknown	No
105	Unknown or mixed	No	Unknown	No
111	Unknown or mixed	No	Unknown	No
113	Unknown or mixed	No	Denmark	No
121	Stearin	No	Unknown	No
122	Unknown or mixed	No	Unknown	No
126	Stearin	Yes	Sweden	No
127	Paraffin	No	Unknown	No
130	Unknown or mixed	No	Denmark	No
131	Unknown or mixed	No	Unknown	No

6.2 Method descriptions

The following chapters give a description of the applied methods, the applied measuring equipment and the climate rooms used during the measurement of candles. The measurement set-up is also described and visualised. The description of the methods applied in the study's analyses of particle emission measured as source concentration and room concentration, and the method applied in the content analysis of lead and nickel in filters, wicks and wax is described in sections 6.2.1, 6.2.2 and 6.2.3. The results of the analyses are presented in sections 6.3, 6.4 and 6.5 respectively.

Unless otherwise stated in the text, the amount of particle emission is stated in the unit # particles/cm³ and the volumetric emission of particles is stated in the unit mg/m³.

6.2.1 Description of method - particle emission at source concentration

One of the aims of the project was to measure the concentration of emitted particles from lit candles so as to be able to compare particle emission from candles for candlesticks made from various kinds of wax. This is done by selecting a measurement method which measures the source concentration of particles from the candles in terms of number of particles and particle size distribution (SMPS measurement) and in terms of particulate matter (DustTrak). In the project priority was given to measuring the source concentration of as many candles as possible in order to get a representative picture of particle emission from white candles for candlesticks on the Danish market. With a view to ensuring that the measurements would be as reproducible as possible, the candle was measured during optimal combustion, i.e. with a steady flame and no draught, sooting etc.

The method used for measuring emissions from candles was selected on the basis that it is the most standardized method for determination of particle emissions from candles, and that this test setup ensures uniform measurement of all candles. The measurement method is based upon an already-existing measurement method, DS/EN15426, which is the recognized method of measuring the soot index of candles.

SMPS – number concentration and size distribution
A SMPS (Scanning Mobility Particle Sizer, model 3080) with nanoDMA (Differential Mobility Analyzer, model 3085) from TSI was used for the measurements. NanoDMA size distributes the particles in up to 167 size fractions. Subsequently, the particles are counted in a CPC (Condensation Particle Counter, model 3776, TSI), so it is possible to read the number concentration (number/cm³) as well as the size distribution. With SMPS, measurements were carried out in the size interval of 4.4-166 nm, which according to experience covers the particle emissions from candles the best.

The scanning time per measurement is 180 seconds with subsequent 30 seconds of ”down” scan (”preparation” for next scan), which gives a classification in app. 100 size fractions (scanning time is of importance to number of possible fractionations).

For the analyses of particle emission at the source, two measurements were carried out and both were carried out in triplicate determination on each candle (total of six measurements/scanning periods on each candle). In addition, measurements were carried out on 2 of each selected candle (candle A and candle B, respectively). That means that 12 measurements were carried out for each selected candle type. The measuring period with SMPS per candle is therefore 21 minutes.

DustTrak – particle mass emission
DustTrak DRX (model 8533 from TSI) was used to measure the particle mass emission from burning candles. The particles are measured simultaneously in five size fractions (PM1, PM2.5, PM4, PM10 and total PM, where PM stands for Particulate Matter). PM2.5 covers the mass of particles with an optical diameter less than 2.5 µm, measured in the unit mg/m³. The time solution is set to 5 seconds, which makes it possible to follow the development of the particle mass emission over time during the measurement period. DustTrak detects particle mass for particles larger than app. 100 nm and up to app. 15 µm in the concentration area of 0.001-150 mg/m³.

Respirable particles are in focus in the project, and therefore only the particle mass emission of particles with an optical diameter less than 2.5 µm (PM2.5) and PMtotal have been included. They create the starting point of the health assessment.

The measurement with DustTrak was started and finalised so the measurement was carried out in the same test period as the measurement with SMPS.

Measurement set-up
The unlit candle for candlesticks was placed in a candleholder. It was placed in a wire screen cylinder (as defined in DS/EN15426, diameter 230 mm, height 300 mm, air permeability 60 ± 5%), and then the height was adjusted so there was 20 cm from the upper edge of the candle to the upper edge of the wire screen cylinder. Then the candle was centred in relation to the wire screen cylinder.

Measuring tubes for SMPS and DustTrak were placed across the upper edge of the wire screen cylinder - see Figure 4.

The filter for passive sampling of smoke from the burning candle was fixed to a glass plate with two pieces of tape, and then it was placed in a stand at the top of the wire screen cylinder – please also refer to Figure 5.

The particle emission measurements were carried out in a climate room (with a floor area of 28 m²) in which temperature, relative humidity and air change can be controlled. For the tests a temperature of 23°C ± 2°C, an air humidity of 50%RH ± 5% RH, and an air change twice an hour[11] were used.

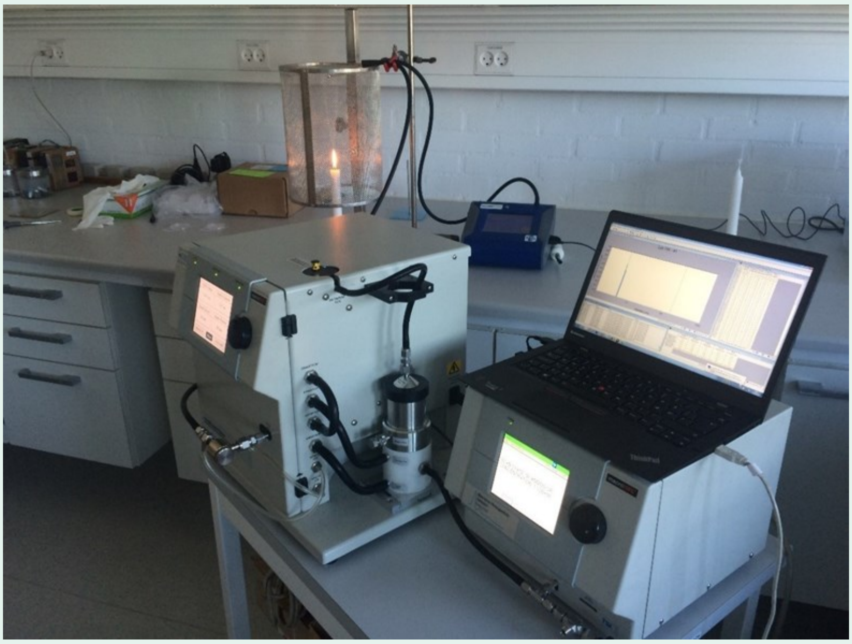

Figure 4
Measurement set-up during measurement of particle emissions from candles with SMPS.

[11] The air change was set higher than a half time per hour that normally is assumed for a room, but due to the set-up with wire screen cylinder and the location of the measuring probe at the top edge of the cylinder that has not influenced the number measurements. Visually it was controlled that the increased air change did not make the candle flicker.

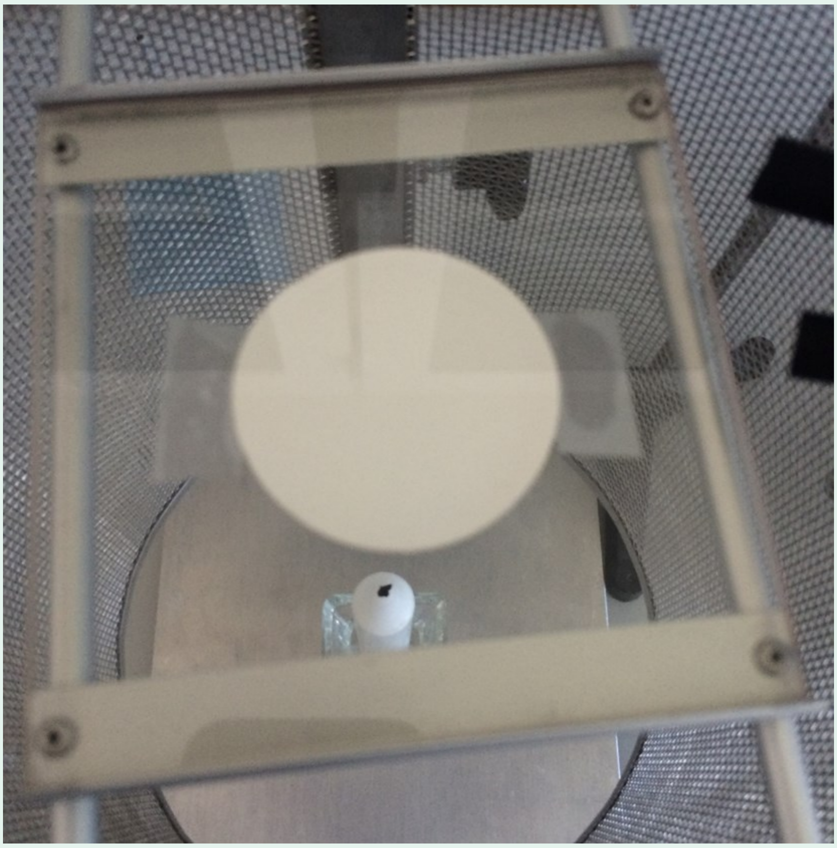

Figure 5
Filter mounted on the glass plate that is placed at the upper edge of the wire screen cylinder. The candle is centred in the wire screen cylinder and ready to be measured.

Timeline for measurements

During start-up, zero measurement was carried out on the instruments to ensure that the systems were tight. In addition, background measurements were carried out on the air in the room in order to be able to correct the subsequently measured results on emissions from candles.

The candle was prepared for measurement and was lit. Then the candle burned for one hour before the actual measurement to ensure that it burned steadily. After the candle had been put out, the air in the room was changed, and the background air was once again measured to ensure that no particle pollution was transferred from the measurement of one candle to another. In that way it was ensured that the particle level in the room was below one per cent compared to the particle level during the previous measurement – see Figure 6.

1 hour	21 minutes	30-60 minutes
Lighting and stable burning	**Measurement**	**Putting out and background level**

Figure 6
Time line for measurement of particle emission from candles.

After measurement, the candle was put in a bag and sent for chemical content analysis. The glass plate with the filter was removed, and the filter was put in a filter container and then sent for chemical content analysis. The glass plate was washed with soap and water and then rinsed in demineralised water before it was quickly dried with a towel and then air dried (in a room outside the climate room).

Filter and glass plate were handled with disposable gloves and a pair of tweezers.

6.2.2 Description of method - particle concentration in the room

Another aim of the project was to carry out an exposure evaluation of the use situation. To this end a measurement was made of particle concentration in a standard room. Based upon the results of the measurements of source concentrations, the decision was taken in this analysis to exclusively focus on candles made from paraffin wax and stearin wax, since these two types of wax had shown the lowest and highest levels of particle number and particulate matter concentrations, as measured in the analysis of source concentration. The candles were selected on the basis of the surveying of candles.

The room concentration of particles emitted from lit candles was measured in the room applying the same methods as used for measurement of source concentration. Measurement of number of particles (PN) and particle size distribution were carried out using SMPS, and particles in the range of 4 to 166 nm were recorded. Particle mass concentration (PM) was likewise measured using DustTrak (see the further description of methods in section 6.2.1).

Room concentration was measured using a climate room 20 m^3 (3.17x2.17x2.88 m^3) in size. The climate room is placed inside an existing laboratory room and consists of laboratory walls on two of the sides and two plastic walls. There is an entrance to the room via a double layer of plastic which covers the outside and inside of the room so as to guarantee that the room is airtight. Inside the room ventilation is regulated by means of an air change 0.5 times per hour. Both temperature (22-28°C) and air humidity (% RH = 39-50) were measured over the study period.

Two monitoring stations were utilized for the measurement of particles in the climate room. The two monitoring stations were placed in diagonally opposite corners, 40 x 60 cm from the walls and 125 cm above the floor (around head height for a seated person). Two lit candles were placed at a distance of approx. 150 cm from both monitoring stations, each in its own wire screen cylinder (230 mm in diameter, 300 mm in height, air permeability 60 ± 5 %) in order to ensure optimal combustion (see Figure 7).

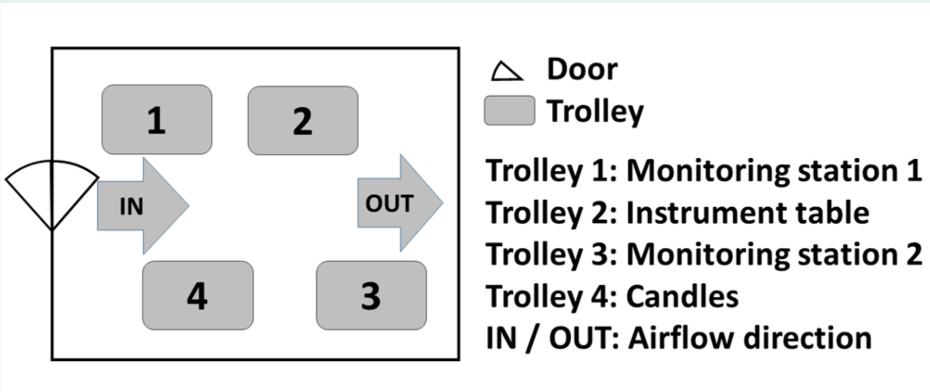

Figure 7
Schematic diagram of climate rooms and test setup used for measurements of room/exposure concentration of particle emission...

For each measurement two candles of the same type were lit and burned until a stable particle concentration was achieved in the climate room (varying from 15 to 50 minutes). After this particulate matter emission was measured using DustTrak on both monitoring stations for the entire duration of the test. Particle number concentration and size distribution were measured in a total of 8 scans (28 minutes) using SMPS. Two scans at a time were carried out, alternating between monitoring stations 1 and 2. Following each series of measurements the climate room was ventilated thoroughly.

Measurements of room concentrations were carried out of 12 different candles, five paraffin wax candles (candles nos. 12, 46, 59, 94 and 127) and seven stearin wax candles (nos. 5, 19, 44, 72, 100, 101 and 102).

6.2.3 Analysis method – content analysis on filters, wicks and parts of candle

Wick and wax were separated by splitting the candle with a sharp scalpel, after which the wick was scraped with the scalpel in order to remove as much of the wax as possible. This separation process is difficult, for which reason the wick samples are considered to be contaminated with a small amount of wax.

Sample preparation - wicks

Sub-samples of wicks, accurately weighed, were dissolved in 6 ml concentrated nitric acid (”sub-boiling quality”) under thermal stress with subsequent dilution to 50 ml with Milli-Q-water and filtration resulting in an acid concentration of 1.7 M. Blanks were prepared correspondingly.

Sample preparation – wax from candles

Sub-samples of wax, accurately weighed, were by means of microwave induced heating prepared with 20 ml 7 M nitric acid (”sub-boiling quality”). The resulting solution was diluted to 50 ml with Milli-Q-water. Blanks were prepared correspondingly.

Sample preparation - filters

The filters were dissolved in 3 ml concentrated nitric acid (”sub-boiling quality”) under thermal stress with subsequent dilution to 25 ml with Milli-Q-water resulting in an acid concentration of 1.7 M. Blanks were prepared correspondingly.

Quantitative analysis by ICP-MS

Samples and blanks were analysed for content of selected elements by ICP-MS with CCT in KED mode and with He as collision gas. Ge, Rh and Re were used as internal standards. Quantification by ICP-MS was carried out with traceable, external standards of the elements. Calibrations were verified with independent, traceable control solutions.

The analysis is carried out as true double determination. The results are stated as an average of these. However, results have been stated for both double determinations of the samples that showed results both above and below the detection limit, and in the cases where the results of the double determinations varied more than the uncertainty of the method.
Detection limit of the method: 0.05 µg/filter or 0.05 mg/kg.

6.3 Particle emission measurement of source concentration

In the following, the results of the particle emission measurements, as measured 20 cm above the flame (the source concentration) are presented, first with a starting point in each individual candle and later according to a type grouping of the candles.

6.3.1 Results of particle number measurement

In general, the particle emission from the burning candles was rather stable in the measuring period, but some candles varied with more that a factor 3 in the stated period. If the variations were due to contamination/impurities in the wax, wick or something entirely different is unknown. One single candle emitted considerably more particles than the other candles (candle 127).

The measured particle diameter was also rather stable during the entire measuring period. Considerable variation was measured for only one candle (candle 127).

Figure 8 gives an example of number count of particles carried out by SMPS. Similar figures for the other candles are presented in annex 2

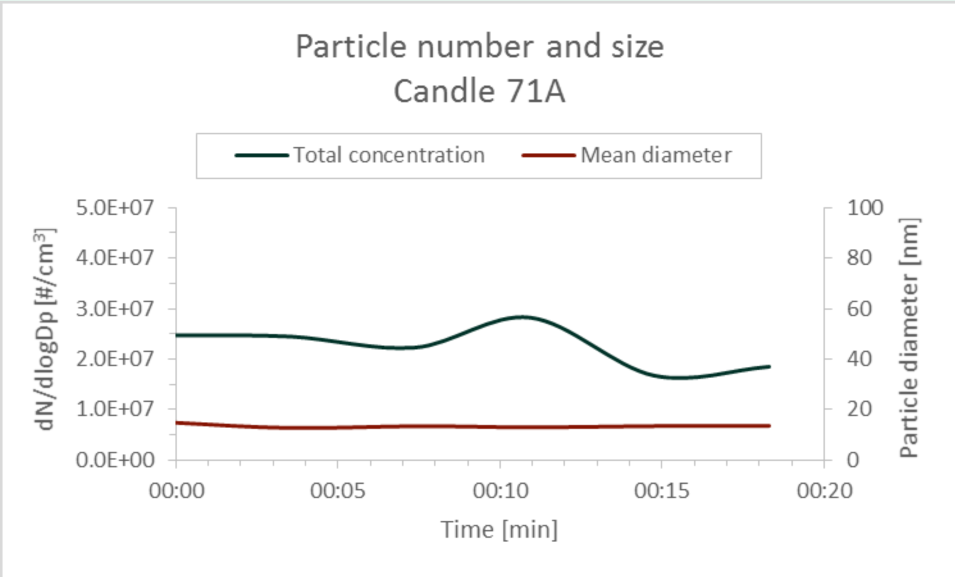

Figure 8
Example of measurement of particle number concentration with SMPS. Number concentrations of around 24 million particles per cm^3 are seen. In this specific case, the wax type is stearin (also refer to table 11). The variations in the particle concentration (DN/DLOGDP) are stated in table 11 as standard deviation between six measuring points for each candle A and B; a total of 12 measuring points.
The right hand axis shows the mean particle diameter of the measured particles stated in nanometer. (As data for SMPS states the starting time of the measurement, it graphically seems as if the measurement only was carried out for app. 18.5 minutes, but the actual total measuring time was app. 21 minutes).

Table 10 lists the average particle number concentration and particle diameter, with specification of spreading, for each of the measured candles. The 32 selected white candles in Table 10 are grouped according to wax type to give a quick overview. The candle number refers to the number that the candle originally was given in the chapter on the survey when identifying different candles. The average particle number concentration measured by SMPS is expressed for each candle and the matching standard deviation is calculated from a total of 12 scans. The average particle diameter of each candle is expressed correspondingly. The wax type is expressed from the information stated on the packaging, meaning that the wax type information is expressed as informed by the point of sale.

Table 10
Emission at the source (20 cm above the flame)
Particle number concentration, - diameter and – mass concentration with matching standard deviations are stated for each tested candle. The results are presented as the mean of the measurements of candle A and B. The candles were tested under optimum conditions and without sooting.

Candle No.	Wax type	Particle no. conc. [#/cm3]	Standard deviation no. conc. [#/cm3]	Particle diameter [nm]	Standard deviation dia. [nm]	Mass conc. [mg/m3]	Standard deviation mass conc. [mg/m3]
12	Paraffin	6.9E+06	2.0E+06	10	0.9	2.1E-04	1.1E-03
46	Paraffin	1.1E+07	8.6E+06	9	1.9	2.8E-03	1.7E-03
59	Paraffin	5.0E+06	3.1E+06	10	1.8	3.2E-03	8.5E-04
94	Paraffin	1.6E+07	2.0E+06	13	1.2	1.0E-02	8.1E-04
127	Paraffin	1.9E+05	2.9E+05	18	10.0	3.4E-03	5.1E-04
5	Stearin	3.1E+07	5.8E+06	15	1.1	1.1E-03	3.2E-04
6	Stearin	1.7E+07	4.4E+06	13	0.6	7.7E-04	5.2E-04
19	Stearin	2.1E+07	5.8E+06	12	1.1	5.6E-04	5.6E-04
21	Stearin	1.7E+07	6.7E+06	12	1.2	1.2E-03	4.2E-04
44	Stearin	2.4E+07	4.7E+06	14	1.2	4.3E-03	7.8E-04
45	Stearin	2.7E+07	5.3E+06	14	1.3	2.9E-03	9.0E-04
69	Stearin	1.8E+07	6.1E+06	13	1.2	4.2E-03	4.4E-04
70	Stearin	1.1E+07	3.9E+06	12	1.3	3.1E-03	6.7E-04
71	Stearin	2.1E+07	3.4E+06	14	1.0	2.3E-03	6.4E-04
72	Stearin	2.0E+07	2.8E+06	13	0.8	3.2E-03	4.9E-04
100	Stearin	3.2E+07	4.7E+06	16	1.5	9.8E-03	1.0E-03
101	Stearin	9.4E+06	3.4E+06	11	1.3	1.2E-02	7.1E-04
102	Stearin	1.8E+07	6.3E+06	13	1.2	1.2E-02	1.5E-03
103	Stearin	3.6E+06	9.4E+05	10	1.3	8.6E-03	3.6E-03
121	Stearin	1.9E+07	5.0E+06	15	1.4	4.0E-03	4.9E-04
126	Stearin	2.3E+07	4.2E+06	14	0.8	4.2E-03	5.0E-04
130	Stearin and paraffin	1.2E+07	3.8E+06	12	1.3	3.5E-03	5.9E-04
40	Fully refined special wax	6.5E+06	3.5E+06	9	1.1	1.7E-03	7.3E-04
76	Recycled stearin	1.3E+07	3.9E+06	13	1.2	4.9E-03	1.4E-03
74	Palm Oil	1.5E+07	3.2E+06	12	1.3	3.3E-03	6.2E-04
82	Unknown	3.4E+06	1.6E+06	9	1.7	7.9E-03	1.1E-03
87	Unknown	4.6E+06	2.0E+06	9	1.4	1.2E-02	8.2E-03
105	Unknown	2.2E+07	5.7E+06	15	1.3	3.9E-03	1.2E-03
111	Unknown	9.9E+05	6.8E+05	7	0.9	3.8E-03	7.8E-04
113	Unknown	1.4E+07	4.6E+06	13	1.6	3.8E-03	5.5E-04
122	Unknown	5.4E+06	2.8E+06	10	1.2	4.6E-03	5.7E-04
131	Unknown	1.1E+07	3.0E+06	14	2.2	3.1E-03	3.1E-04

Table 10 shows that the particle size in general is more or less the same for the different candles. That is assumed to be due to the burning type (candlestick candles) and the burning process (steady burning without sooting). It is observed that the candels emits particles at a size of 7-18 nm. With an aerodynamic particle diameter in that range the particles are so small that persistent particles immediately could translocate from the lung tissue (the alveolars) to the bloodstream, and from there be transported around in the body.

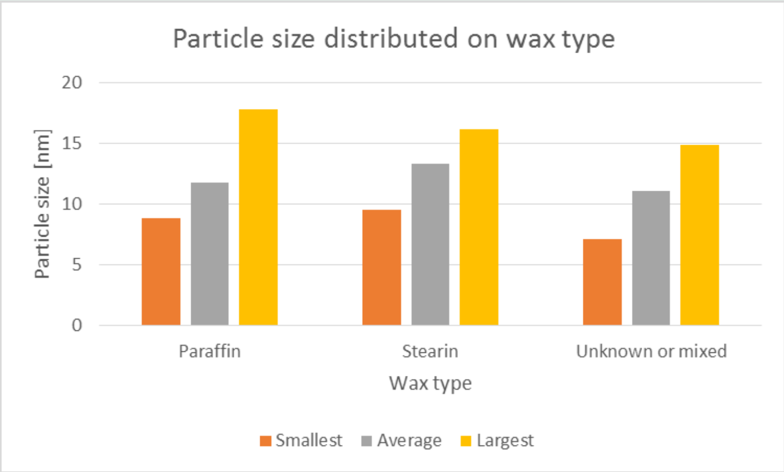

Figure 9
The average particle size of each wax type is shown with the smallest, the average and the largest measured particle size.

As appears in Figure 9, the size interval is rather narrow for the emitted particles from candles – if it is compared to the concept of *respirable particles* that are defined as particles below 2.5 µm (2,500 nm). There is a somewhat larger spread in the particle size emitted from paraffin candles than from stearin candles. On the other hand, the data foundation is better for stearin candles as more of that type of candles were tested (16 stearin candles against 5 paraffin candles).

No study of particle size has been carried out over time, meaning if a change takes place in the particle size in the different burning phases; the lighting phase, stable burning phase and the smouldering phase of the candle. Neither has it been possible to investigate the particle size distribution of all 32 candles (64 with double determination) within the framework of this project. However, a random candle was chosen (candle number 100 made of stearin), where a calculation of the particle size distribution for one scan was carried out – please also refer to Figure 10 that shows that the concentration of particles is largest in the size interval of 5-30 nanometer, after which the particle concentration is very low.

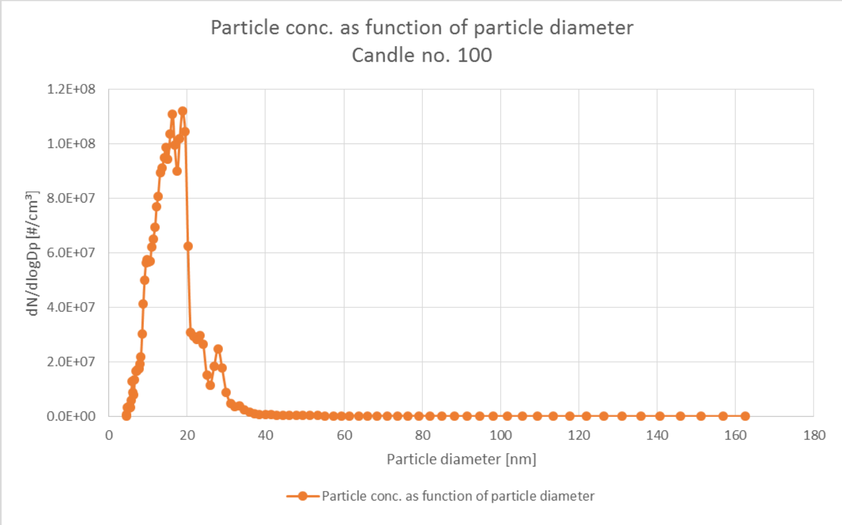

Figure 10
The figure shows the particle concentration as function of the diameter of candle 100. It appears that the concentration is largest in the size interval 5-30 nanometer after which, the concentration is very low.

6.3.2 Results of particle mass measurements

In general, low concentrations were measured in the particle mass measurements that were carried out with DustTrak. Most candles emitted a very small amount of particle mass as the emitted particles are so small that they hardly could be detected with the instrument, and only very few emitted more than 0.01 mg/m^3. An example of one of these candles can be seen in Figure 11.

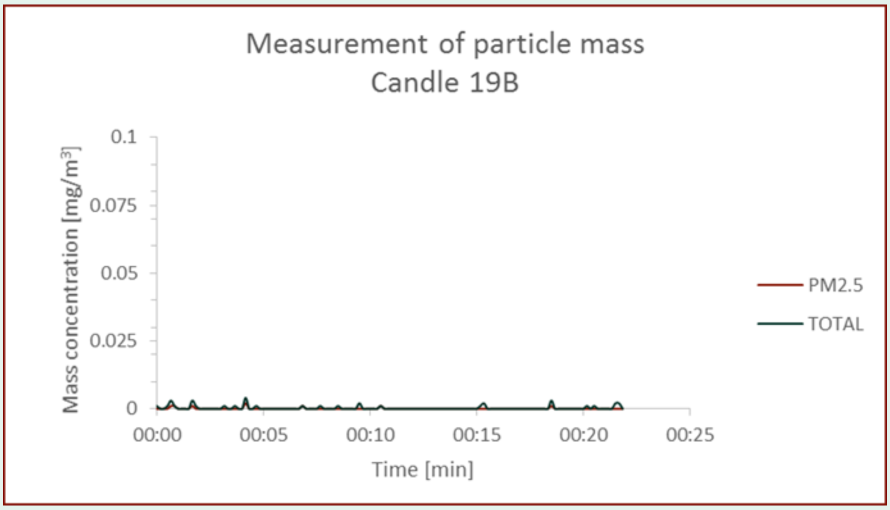

Figure 11
Example of measurement of particle mass concentration with DustTrak. As was the case with nearly all measurements on burning candles, hardly any “large” particles were measured in the smoke – please also refer to appendix 3.

The only candle that emitted rather large peaking particle mass concentrations in the course of the 21 minute long measuring period was candle 87 (87a as well as 87b). Those concentrations reached app. 0.06 mg/m^3, see Figure 12. Similar figures for the other candles are presented in annex 3.

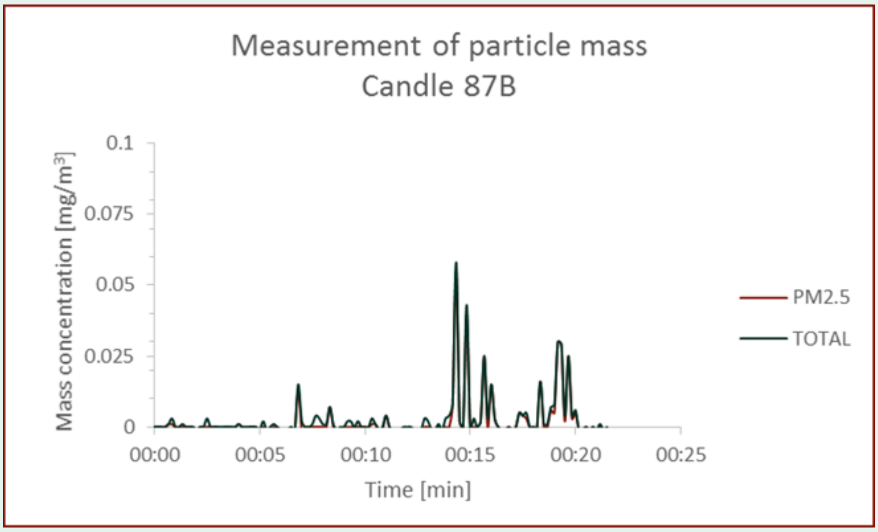

Figure 12
Only candle 87 showed emission of particle mass during the measurements that were carried out. The measurement carried out on candle 87b is shown here. It is obvious that there are very large peaks from time to time. PM2.5 and PM total follow each other, which indicates that especially particles with an optic diameter below 2.5 micrometre dominate the particle mass measurements.

6.3.3 Discussion of particle emission measurements of source concentration

The 32 selected candles were all categorised according to the information the manufacturers/ point of sales had stated on the packaging. The measured candles were categorised in the following three main categories: *stearin, paraffin* and *Unknown or mixed:*

- The category *Stearin*: It appears clearly from the information on the packaging that the candles are made of stearin (the wax type is stearin).
- The category *paraffin*: It appears clearly from the information on the packaging that the candles are made of paraffin.
- The category *Unknown or mixed*: Either 1) It does not appear clearly from the information on the packaging, which kind of wax the candles are made of; or 2) It appears clearly from the information on the packaging that a mixture of several wax types has been used; or 3) A wax making procedure is stated on the packaging without clearly stating, which type of wax is in question (e.g., fully refined wax); or 4) Other types of wax (e.g. palm oil).

The three main categories make it possible to carry out a comparison between the various types of candles. Table 12 states how many candles were investigated from each of the three categories. In addition, the smallest average particle number concentration, the average of the average particle number concentration and the largest average particle number concentration for each of the three categories is stated. In order to make that easier to read, they will from now on be called smallest particle concentration, average particle concentration and largest particle concentration.

Table 11
The wax types were grouped, and the number of candles belonging to each wax type was counted. For each group an average particle number concentration was calculated according to the calculated average values stated in table 11 for each candle. The largest and smallest values in each group have also been stated.

Wax type	No. of candles from each wax type	Smallest average particle no. conc. [#/cm³]	Average particle no. conc. [#/cm³]	Largest average particle no. conc. [#/cm³]
Paraffin	5	1.9E+05	7.8E+06	1.6E+07
Stearin	16	3.6E+06	1.9E+07	3.2E+07
Unknown or mixed	11	9.9E+05	9.8E+06	2.2E+07

The values in Table 11 are shown graphically in Figure 13.

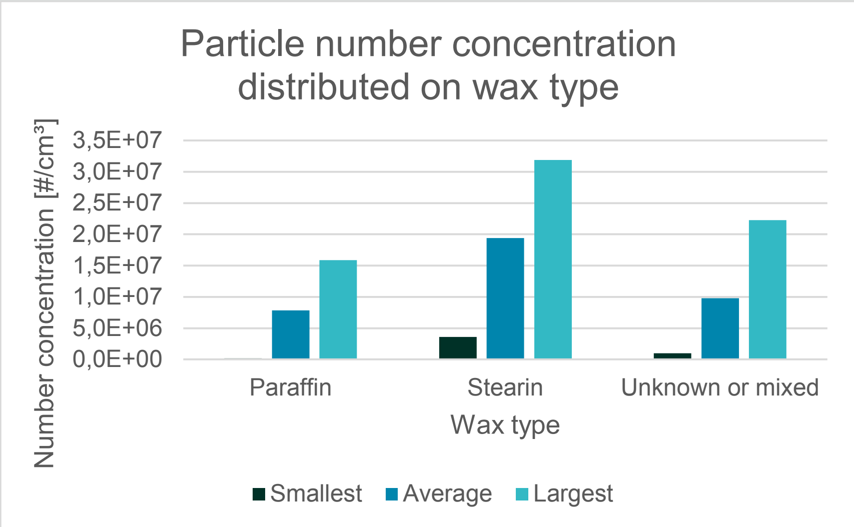

Figure 13
The average measured particle number concentration has been calculated for each of the three main wax type categories. The smallest and largest measured value has also been stated. Please note that the smallest measured value for paraffin is so low that it cannot be seen in the graph – please also refer to table 12.

Candles made of the wax type stearin in general emit most particles with an average emission of 19 million particles/cm³. There is a great difference in the number of emitted particles in this category; from app. 4 million particles/cm³ from the candle that emits the least, to 32 million particles/cm³ from the candle that emits the most.

In general, candles made of paraffin have the lowest emission of particles. The candles in that category in average emit 7.8 million particles/cm³. However, in this category there is also a great difference in the number of emitted particles. The candle from the category *paraffin* that emits most particles emits 16 million particles/cm³, which is below the average number of emitted particles for candles in the category *stearin*. The candle in the category *paraffin* that emits the smallest amount of particles only emits 1.3% particles compared to the average of the candles in the other categories. For this candle, an average of 0.2 million particles/cm³ were measured.

The category *Unknown or mixed* covers other wax types that either have not been stated on the packaging and therefore are *Unknown*, or that did not precisely come within the categories *stearin or paraffin*, e.g., the candle is made of ”stearin and paraffin” or ”recycled stearin”. The measurements of the particle emissions from the candles in this category are number-wise between the *paraffin* group and the *stearin* group. Wax types of both stearin and paraffin can be found in this group, and therefore it is expected that very high and very low particle number concentrations will be measured.

As appears in Figure 11, hardly any particle mass emissions were measured from the burning candles. Only one single candle, candle no. 87 – Figure 12, showed a pronounced emission of particle mass. Candle 87 is categorised under *Unknown or mixed*, which means that no further information is available about the wax type. A rather expensive candle is in question. The country of origin is unknown. Therefore, it has not been possible to be more specific about a possible reason for the increased particle mass emission.

The particle mass concentrations can be informed in the same way as the particle number concentrations. Table 12 shows the values of the mass concentrations.

Table 12
The wax types were grouped, and the number of candles belonging to each candle type was counted. For each group an average particle mass concentration was calculated based on the calculated average values stated in table 11 for each candle. For each candle, the largest and smallest values in each group have also been stated.

Wax type	No. of candles from each wax type	Smallest average particle no. conc.	No. of candles from each wax type	Smallest average particle no. conc.
Paraffin	5	2.1E-04	3.9E-03	1.0E-02
Stearin	16	5.6E-04	4.6E-03	1.2E-02
Unknown or mixed	11	1.7E-03	4.8E-03	1.2E-02

The values in Table 12 are shown graphically in Figure 14.

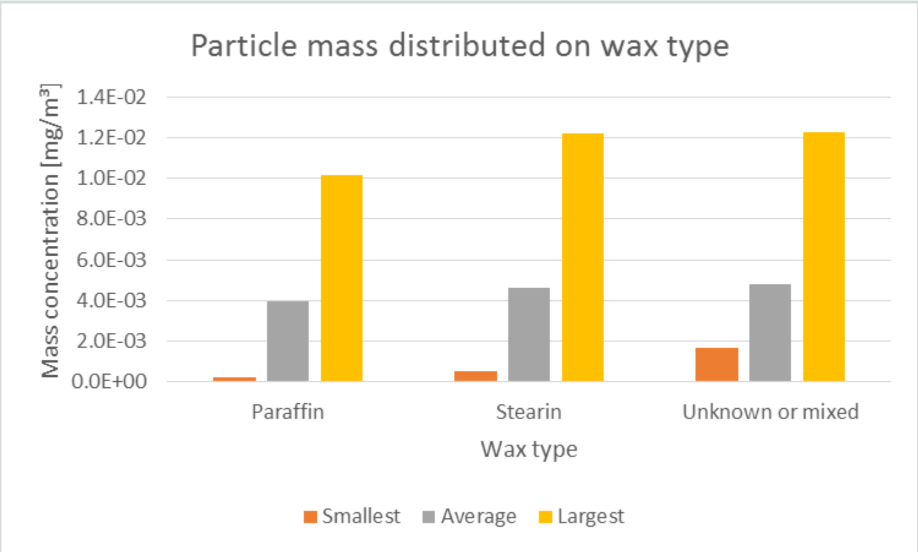

Figure 14
For each of the three main categories of wax types, the average measured particle mass concentration has been calculated. The smallest and largest measured values are also stated. Please also refer to table 13.

6.3.4 Part conclusion from particle source emission measurements

Based upon the measurement of 32 candles, it can be concluded that paraffin candles in general emit less particles than for instance candles of the wax type stearin.

As measured just above the flame The average size of particles emitted from the tested candle is between 7 and 18 nm, which is to say very small particles which have a relatively narrow size interval when compared with *respirable particles*, which are particles less than 2.5 μm (2,500 nm) in size.There is no substantial difference in size of particles between particles emitted from paraffin candles versus particles emitted from stearin candles.

One paraffin candle emits significantly less particles than all the other tested candles. One single candle with unknown type of wax emits a particle mass of up to app. 0.06 mg/m^3.

All candles, irrespective of wax type, emitted a very low level of particulate matter within the measureable range (particles 100 nm to 15 μm in size). It should be emphasized that all candles primarily emit relatively small particles with an average particle diameter of 7-18 nm, which lies outside of the range measurable by the DustTrak apparatus

6.4 Results of particle emission measurements in a room 20 m^3 in size

In the following we will present the results of particle emission measurements which are intended to represent the exposure concentration for users of candles. The emission from 12 different types of candle was measured by simultaneous burning of two candles. Measurement was carried out in a climate room 20 m^3 in size, corresponding to the average room included in the exposure scenarios outlined in chapter 7. Room concentrations were measured by burning candles of the paraffin wax type (five different types) and candles of the stearin wax type (seven different types).

Table 13 presents particle number concentration, average particle size and particle mass concentration (measured as PM2.5) of the 12 selected candles. The values presented in the table show the calculated average of the values measured at the two monitoring stations in the room.

Table 13
Room concentration when burning two candles simultaneously. Particle number concentration, diameter and mass concentration with associated standard deviation is presented for each of the tested candle types as an average of two measurements carried out in a room 20m3 in size when burning two candles simultaneously. The candles are tested under optimal conditions and without sooting.

Candle No.	Wax type	Particle no. conc. [#/cm3]	Standard deviation no. conc. [#/cm3]	Particle diameter [nm]	Standard deviation dia. [nm]	Mass conc. [mg/m3]	Standard deviation mass conc. [mg/m3]
12	Paraffin	1.3E+06	2E+05	22	1	0.003	0.002
46	Paraffin	9.7E+05	2E+05	18	1	0.005	0.002
59	Paraffin	1.1E+06	2E+05	20	1	0.008	0.001
94	Paraffin	8.9E+05	4E+05	16	2	0.010	0.002
127	Paraffin	3.2E+05	7E+04	11	1	0.001	0.001
5	Stearin	1.7E+06	4E+05	21	2	0.020	0.003
19	Stearin	1.7E+06	4E+05	25	2	0.005	0.001
44	Stearin	1.6E+06	3E+05	24	2	0.000	0.001
72	Stearin	1.5E+06	3E+05	20	4	0.012	0.003
100	Stearin	1.5E+06	2E+05	26	1	0.007	0.001
101	Stearin	1.6E+06	3E+05	22	1	0.013	0.002
102	Stearin	1.6E+06	3E+05	22	1	0.004	0.001

Table 14 states how many candles of the paraffin wax and stearin wax types were tested, together with information concerning the average particle number concentration, particle size and particulate matter concentration (PM2.5) for each type of wax (with the lowest and highest values in brackets).

Table 14
Emission in Room (measured 1.5 m from the lit candle).
The average particle number concentration, diameter and mass concentrations are shown in table 13 for, respectively, paraffin candles and stearin candles when burning two candles simultaneously. Rendered as an average with minimum and maximum values in brackets.

Wax type	Candle No.	Particle no. conc. [#/cm3]	Particle diameter [nm]]	Mass conc. [mg/m3]
Paraffin	5	9,16E+05 (3,2E+05 - 1,3E+06)	17,4 (11-22)	5,4E-03 (1,2E-03 – 1,0E-02)
Stearin	7	1,6E+06 (1,5E+06 - 1,7E+06)	22,9 (21- 26)	8,7E-03 (0 – 2,0E-02)

6.4.1 Particle number

The particle number concentration in the room for the candles tested was measured in concentrations of between 320,000 and 1.7 million # particles/cm^3 when two candles were burned simultaneously. The highest particle number concentration in the climateroom was observed with the combustion of candles made of stearin. The measured room concentrations were higher for all the included candles of stearin compared with the room concentrations measured while burning candles of paraffin (see Figure 15).

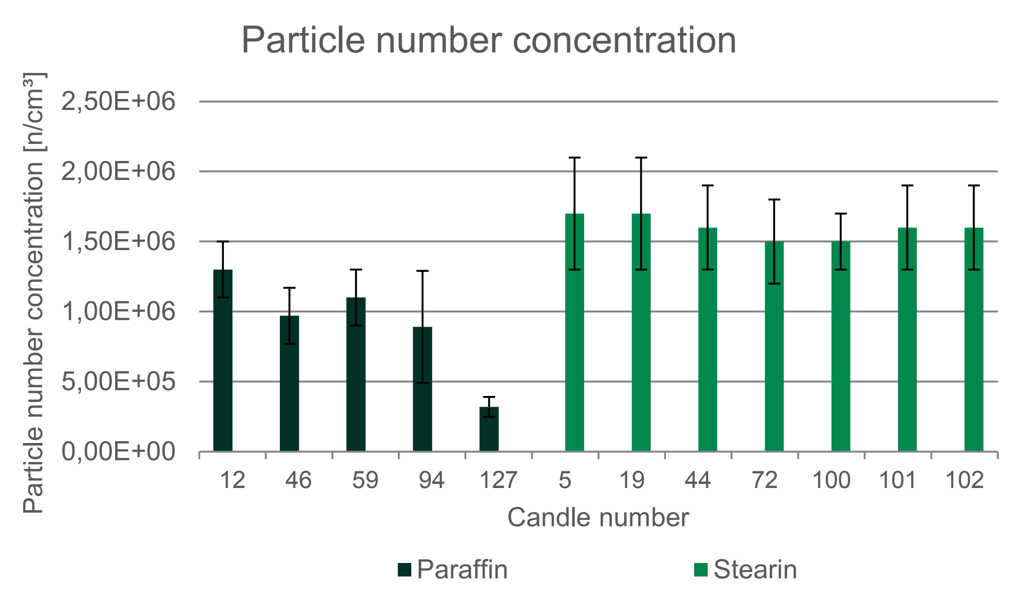

Figure 15
Number concentration of particles emitted from the lit candles. The graph shows the average number of emitted particles for each type of candle when two candles were burned simultaneously. The uncertainty reflects the variation between the two monitoring stations over the period in which the measurements were taken.

6.4.2 Particle size

The average particle diameter of particles measured in the room was greater for stearin candles (22.9 nm) than for paraffin candles (17.4 nm). The average particle size of the emission varied more between the candles made of paraffin than between the candles made of stearin (see figure 16).

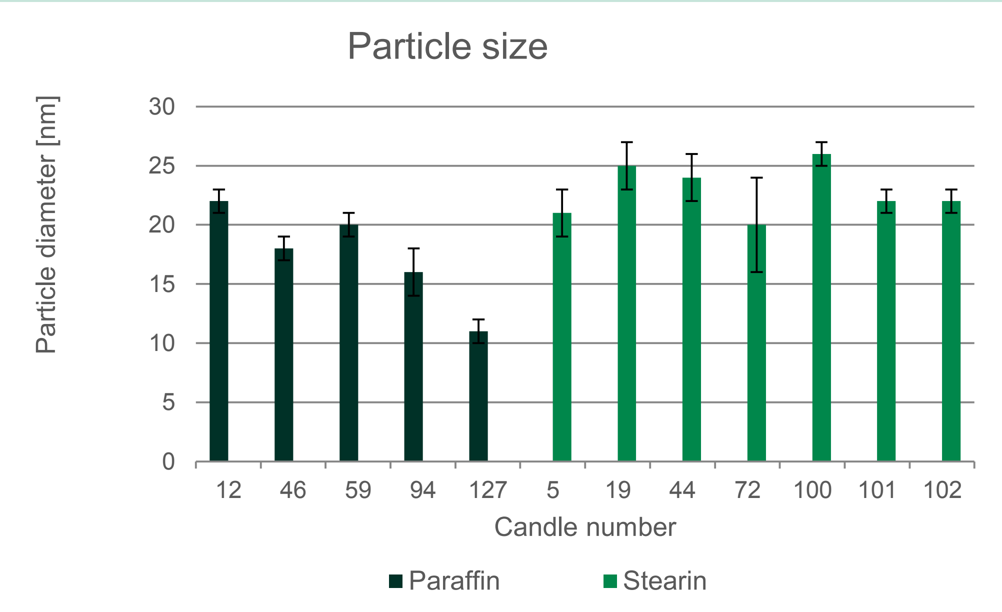

Figure 16
The average particle size is shown for each candle number. The uncertainty reflects the variation between the two monitoring stations over the period in which the measurements were taken.

6.4.3 Particulate matter

Particulate matter concentration (PM2.5) for all candles was relatively low and close to the measuring apparatus' detection limit of 0.001 mg/m^3. The higest measured particle mass was observed while burning a candles made of stearin. The stearin candles emitted on average slightly more particle mass than the candles made of paraffin (Figure 17).

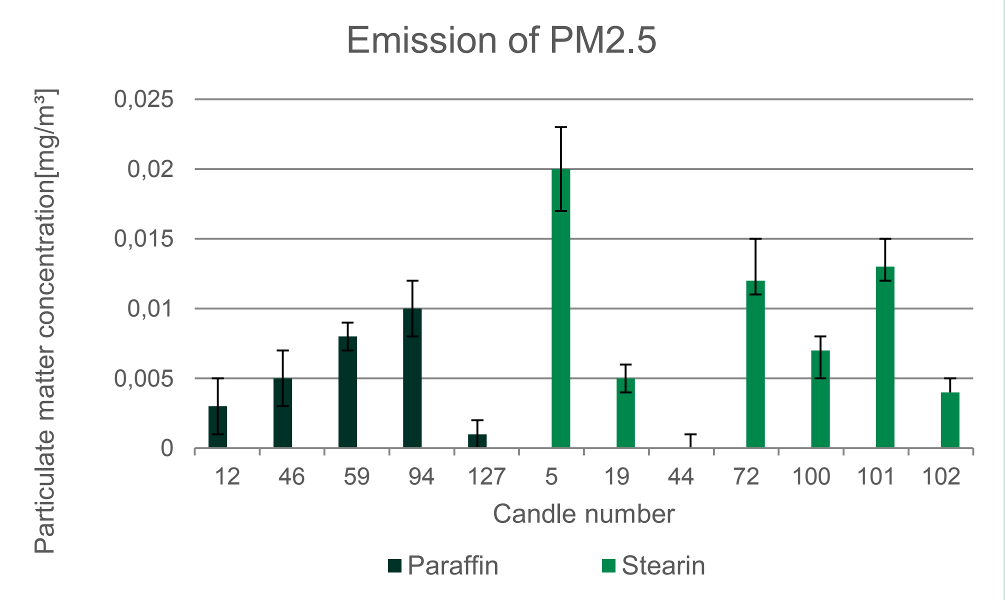

Figure 17
Mass concentration (PM2.5) of particles emitted from the lit candles. The graph shows the average number of emitted particles for each type of candle when two candles were burned simultaneously. The uncertainty reflects the variation between the two monitoring stations over the period in which the measurements were taken.

6.5 Comparison of source and room concentration measurements

The measurements for room emissions (shown in tables 13 and 14) may be compared with the measurements of source concentration taken measured directly above the candle (shown in tables 10 and 11). The average particle number concentration, particle size and particulate matterparticle mass concentration (PM2.5) recorded in the two tests set of experiments for each of the wax types, paraffin and stearin, is shown in Table 15. The measurements of room concentration are multiplied by a factor of 0.5 in order to calculate the level per candle.

Table 15
Emissions in room and at source
Particle number concentration, average diameter and mass for each of the wax types, paraffin and stearin. Based on values in Table 10 (measurement at source directly above the burning candle) and Table 13 (measurement in the room) and rendered as an average (with the lowest and highest values in brackets) for the respective parameters.

Test	Wax type	Number of candles	Particle number concentration [n/cm³]	Particle diameter (nm)	Particulate matter concentration [n/cm³]
Room (measured 1.5 m from the lit candle)	Paraffin	5	4.6E+05 (1.6E+05 – 6.5E+05)	17.4 (11-22)	2.7E-03 (5.0E-04 – 5.0E-03)
	Stearin	7	8.0E+05 (7.5E+05 – 8.5E+05)	22.9 21-26	4.4E-03 (0.0 – 1.0E-2)
Source (measured 20 cm above the flame)	Paraffin	5	7.8E+06 (1.9E+05 – 1.6E+07)	12 (9 - 18)	3.9E-03 (1.2E-03 – 1.0E-02)
	Stearin	16	1.9E+07 (3.6E+06 – 3.2E+07)	13.4 (10 - 16)	4.6E-03 (5.6E-04 – 1.2E-02)

As was also the case with the particle number concentration measured at the source, the particle number concentration in the room was generally lower for the paraffin candles analysed than for the stearin candles analysed. With respect to the individual candles there was no clear correlation between particle number concentration at source and particle number concentration recorded in the room. The relationship between particle number concentration at source and in the room varied by a factor of between 1 and 43 for the candles analysed, with an average of 23. Thus relative identical room particlenumber concentrations were recorded for all candles of the stearin wax type irrespective of the highly variable source concentrations recorded for the same candles.

The emitted particles measured in the room had a mean diameter of between 11 and 26 nm, which is greater than the mean diameter of the particles measured close to the source, which was between 7 and 18 nm. This result indicates that an agglomeration of particles occurs in the room. The degree of agglomeration appears to vary between particles from paraffin candles and particles from stearin candles. The speed of the agglomeration process has not been investigated in ths study. Where the average mean diameter was identical at source (i.e. directly above the candle) - measured as 12 nm and 13 nm for paraffin and stearin respectively - particles from stearin candles agglomerated to larger particles out in the room, where the average mean diameter was recorded as being 17 nm and 23 nm for paraffin and stearin candles respectively. The agglomeration of small particles to bigger particles was not observed to a degree, which could be detected with DustTrak.

All particle mass concentrations were low and lay close to the method's lower detection limit. The particulate matter concentrations measured in the room were at the same level as at the source. A potential explanation for this is that emissions from all candles, measured both at source and out in the room, primarily consist of particles of a small size with an average particle mean diameter of between 9 nm and 26 nm, which lies outside the detectible range of the DustTrak apparatus, and thus does not significantly contribute to the measured particulate matter concentration. Agglomeration of smaller particles to larger particle was not observed to a degree that was detectable with DutsTrak.

6.5.1 Sub-conclusion concerning particle emission measurements

Based upon the measurement of 12 different candles it can be concluded that paraffin candles in general emit fewer particles than stearin wax candles. The difference in particle number concentration between the two wax types was however smaller out in the room than at the source.

In the room, the average mean particle size emitted from the candles tested was 17 nm for paraffin candles and 23 nm for stearin candles, which demonstrates the agglomeration of particles out in the room in terms of particle size measured in source concentration. Based on the observations in this project particles from stearin candles agglomerated out in the room to a greater extent than particles from paraffin candles. However, the average mean particle size for all candles remained very low, and on an order of magnitude which would allow for the translocation of persistent particles from lung tissue (alveoli) to the bloodstream and from there to circulate around the body.

The particulate matter concentration in the room was low for all candles and on the same order of magnitude as the particulate matter measured as source concentration.

6.5.2 Discussion of particle emission measurements

Currently, there are no limit values for particle number concentrations. Therefore, measurements carried out with SMPS are compared with either pervious studies or empirical values.

The number of emitted particles can also be compared to the number of emitted particles during ordinary cooking at home. Measurements have been carried out of the number of ultrafine particles when baking bread or frying meat on a hot pan. That will typically give 1 million particles per cm^3, which is comparable to room concentrations of the emission from candles observed in this study.

Another frequently used empirical value for the assessment of the particle number concentration is the concentration of ultrafine particles in the air on H. C. Andersen's Boulevard (very busy street) in Copenhagen. On an ordinary workday, the concentration will typically be 30,000 - 40,000 particles/cm^3. It should be stressed that it has not been investigated, which type of particles are in question when measuring candles; that is, if inorganic salts, organic (semi)volatile particles or black carbon are in question. Only quantification has been carried out. Please refer to chapter 7 for a health assessment of the particle number.

6.6 Results of chemical analyses of lead and nickel

After the particle emission measurements had been carried out, the candles were chemically analysed for content of lead and nickel in wax and wicks and in filters that had been used for sampling during burning. The analysis data from the chemical analyses are shown below in Table 16.

The analyses were carried out as true double determinations, and the results are stated as their average. However, results have been stated for both double determinations of the samples that show results both above and under the detection limit of 0.05 µg/filter and 0.05 mg/kg, respectively, for wax and wicks, and for the samples where the results of the double determinations vary more than the uncertainty of the method. Please note that the results are stated in different units.

6.6.1 Analyses of lead and nickel on filters

When analysing the filters, neither lead nor nickel was detected on the filters from burning on the main part of the candles, please see Table 16. However, lead was detected on the filters from candle 111 and 122 in concentrations of 0.60 µg/filter and 0.16 µg/filter for at least one of the tested candles, respectively, and nickel was detected on filters from candle 5, 21 and 103 in concentrations of up to 0.17 µg/filter, 0.11 µg/filter and up to 0.11 µg/filter for at least one of the tested candles, respectively.

Table 16
The table shows the content of lead and nickel sampled on filters in connection with the burning of candles. Results are stated for both double determinations of the samples that show results above and below the detection limit, and for the samples where the results of the double determinations vary more than the uncertainty of the method.

Sample no.	Wax type	Lead (when burning) Results in µg/filter	Nickel (when burning) Results in µg/filter
Background, filter	-	<0.05	<0.05
Candle 5A, Candle 5B, filter	Stearin	<0.05	0.17/<0.05
Candle 6A, Candle 6B, filter	Stearin	<0.05	<0.05
Candle 12A, Candle 12B, filter	Paraffin	<0.05	<0.05
Candle 19A, Candle 19B, filter*	Stearin	<0.05	<0.05
Candle 21A, Candle 21B, filter	Stearin	<0.05	0.11/<0.05
Candle 40A, Candle 40B, filter	Fully refined special wax	<0.05	<0.05
Candle 44A, Candle 44B, filter*	Stearin	<0.05	<0.05
Candle 45A, Candle 45B, filter	Stearin	<0.05	<0.05
Candle 46A, Candle 46B, filter	Paraffin	<0.05	<0.05
Candle 59A, Candle 59B, filter	Paraffin	<0.05	<0.05
Candle 69A, Candle 69B, filter*	Stearin	<0.05	<0.05
Candle 70A, Candle 70B, filter*	Stearin	<0.05	<0.05
Candle 71A, Candle 71B, filter	Stearin	<0.05	<0.05
Candle 72A, Candle 72B, filter	Stearin	<0.05	<0.05
Candle 74A, Candle 74B, filter	Palm Oil	<0.05	<0.05
Candle 76A, Candle 76B, filter	Recycled stearin	<0.05	<0.05
Candle 82A, Candle 82B, filter	Unknown	<0.05	<0.05
Candle 87A, Candle 87B, filter	Unknown	<0.05	<0.05
Candle 94A, Candle 94B, filter	Paraffin	<0.05	<0.05
Candle 100A, Candle 100B, filter	Stearin	<0.05	<0.05
Candle 101A, Candle 101B, filter	Stearin	<0.05	<0.05
Candle 102A, Candle 102B, filter	Stearin	<0.05	<0.05
Candle 103A, Candle 103B, filter	Stearin	<0.05	<0.05/0.11
Candle 105A, Candle 105B, filter	Unknown	<0.05	<0.05
Candle 111A, Candle 111B, filter	Unknown	0.60 (0,63/0,56)	<0.05
Candle 113A, Candle 113B, filter	Unknown	<0.05	<0.05

Sample no.	Wax type	Lead (when burning) Results in µg/filter	Nickel (when burning) Results in µg/filter
Candle 121A, Candle 121B, filter	Stearin	<0.05	<0.05
Candle 122A, Candle 122B, filter	Unknown	0.089/0.16	<0.05
Candle 126A, Candle 126B, filter	Stearin	<0.05	<0.05
Candle 127A, Candle 127B, filter	Paraffin	<0.05	<0.05
Candle 130A, Candle 130B, filter	Stearin and paraffin	<0.05	<0.05
Candle 131A, Candle 131B, filter	Unknown	<0.05	<0.05

** The candle has the Nordic Ecolabel*

6.6.2 Content analyses of lead and nickel in wax and wicks from candles

The chemical analyses for content of lead and nickel showed that the main part of the candles do not contain lead or nickel in the wax. However, a content of lead was detected in four of the candles (candle 71, 87, 111 and 122) in concentrations from 0.11 mg/kg to 0.37 mg/kg, whereas only two of the candles contained nickel (candle 19 and 44) in concentrations of 0.010 mg/kg to 1.3 mg/kg.

On the other hand, the chemical analyses showed that a large part of the wicks contained lead, meaning 26 out of the 32 samples. The concentrations vary from 0.054 mg/kg to 9 mg/kg. Wicks in nine of the candles contained nickel in concentrations from 0.082 mg/kg to 2.5 mg/kg.

Table 17
The amounts listed in the table show the results of the chemical analyses regarding content of lead and nickel in wax and wicks. Results are stated for both double determinations of the samples that show results above and below the detection limit, and for the samples where the results of the double determinations vary more than the uncertainty of the method.

		Wax		Wicks	
Sample No.	Wax type	Lead [mg/kg]	Nickel [mg/kg]	Lead [mg/kg]	Nickel [mg/kg]
Candle 5A, Candle 5B	Stearin	<0.05	<0.05	0.43/0.16	0.69/<0.05
Candle 6A, Candle 6B	Stearin	<0.05	<0.05	0.22/0.12	<0.05/2.5
Candle 12A, Candle 12B	Paraffin	<0.05	<0.05	0.20/<0.05	<0.05
Candle 19A, Candle 19B *	Stearin	<0.05	0.10/0.16	<0.05/0.054	0.082/0.29
Candle 21A, Candle 21B	Stearin	<0.05	<0.05	0.45/0.29	0.13/<0.05
Candle 40A, Candle 40B	Fully refined special wax	<0.05	<0.05	<0.05/3.5	<0.05/0.22
Candle 44A, Candle 44B *	Stearin	<0.05	1.3/<0.05	<0.05/0.073	0.093/<0.05
Candle 45A, Candle 45B	Stearin	<0.05	<0.05	0.14/0.073	<0.05
Candle 46A, Candle 46B	Paraffin	<0.05	<0.05	0.19/0.11	<0.05/0.29
Candle 59A, Candle 59B	Paraffin	<0.05	<0.05	0.40/0.22	<0.05
Candle 69A, Candle 69B *	Stearin	<0.05	<0.05	0.31/0.22	0.21/<0.05
Candle 70A, Candle 70B *	Stearin	<0.05	<0.05	0.19/0.43	<0.05
Candle 71A, Candle 71B	Stearin	<0.05/0.16	<0.05	0.29 (0,30/0,29)	<0.05
Candle 72A, Candle 72B	Stearin	<0.05	<0.05	0.092/0.15	<0.05
Candle 74A, Candle 74B	Palm oil	<0.05	<0.05	<0.05/1.6	<0.05
Candle 76A, Candle 76B	Recycled stearin	<0.05	<0.05	<0.05/0.066	<0.05
Candle 82A, Candle 82B	Unknown	<0.05	<0.05	<0.05	<0.05
Candle 87A, Candle 87B	Unknown	<0.05/0.37	<0.05	0.069/0.28	<0.05
Candle 94A, Candle 94B	Paraffin	<0.05	<0.05	0.094/0.053	<0.05
Candle 100A, Candle 100B	Stearin	<0.05	<0.05	<0.05	<0.05
Candle 101A, Candle 101B	Stearin	<0.05	<0.05	<0.05/0.080	<0.05
Candle 102A,	Stearin	<0.05	<0.05	0.056/<0.05	<0.05

		Wax		Wicks	
Sample No.	Wax type	Lead [mg/kg]	Nickel [mg/kg]	Lead [mg/kg]	Nickel [mg/kg]
Candle 102B					
Candle 103A, Candle 103B	Stearin	<0.05	<0.05	<0.05	<0.05
Candle 105A, Candle 105B	Unknown	<0.05	<0.05	<0.05	<0.05
Candle 111A, Candle 111B	Unknown	<0.05/0.11	<0.05	1.0/9.0	1.6/<0.05
Candle 113A, Candle 113B	Unknown	<0.05	<0.05	0.25/<0.05	<0.05
Candle 121A, Candle 121B	Stearin	<0.05	<0.05	0.31/<0.05	<0.05
Candle 122A, Candle 122B	Unknown	0.22/0.13	<0.05	0,22 (0,24/0,20)	<0.05
Candle 126A, Candle 126B	Stearin	<0.05	<0.05	<0.05	<0.05
Candle 127A, Candle 127B	Paraffin	<0.05	<0.05	<0.05/0.082	<0.05
Candle 130A, Candle 130B	Stearin and paraffin	<0.05	<0.05	<0.05/0.077	<0.05
Candle 131A, Candle 131B	Unknown	<0.05	<0.05	<0.05	<0.05

** The candle has the Nordic Ecolabel.*

6.6.3 Summary of analysis results

As stated earlier, the results appear for both double determinations of the samples that show results above and below the detection limit, and for the samples where the results of the double determinations vary more than the uncertainty of the method. It is assessed that the deviations in the double determinations are due to inhomogeneity in the single parts of the candles, and that is reflected in the results of the content analyses and the results of the burning.

In general, more lead and nickel were detected in the wicks of the candles than in the wax, and more lead than nickel was detected in the wicks of the candles. As mentioned earlier, lead was detected in wicks in 26 out of the 32 candles.

None of the four candles with the Nordic Ecolabel showed a content of lead and nickel during burning, but a content of lead and /or nickel was detected in all of the four candles with the Nordic Ecolabel, and that was mainly in the wicks. However, the detected amounts were low, corresponding to a lead content of 0.054-0.43 mg/kg and a nickel content of 0.082-1.3 mg/kg. The levels of the candles with no Nordic Ecolabel are more or less the same; however, with the exception of candle 6 and candle 111. Candle 111 has a content of lead and nickel of up to 9 mg/kg and 1.6 mg/kg in the wick, respectively, and candle 6 has a content of nickel of 2.5 mg/kg in the wick.

If the results of the filters are compared with the results of the single parts of the candles, it appears that nickel on the filters from burning of candle 5 (up to 0.17 µg/filter) and candle 21 (up to 0.11 µg/filter) must originate from the wick where the contents are up to 0.69 and up to 0.13 mg/kg, respectively. Nickel on the filter from the burning of candle 103 (up to 0.11 µg/filter) cannot be recovered in wax or wick. The content of lead on the filters from candle 111 (0.60 µg/filter) and candle 122 (up to 0.16 µg/filter) may originate from both wax and wick. The wax contains up to 0.11 mg/kg and up to 0.22 mg/kg, respectively, and the wicks contain up to 9 mg/kg and 0.22 mg/kg for candle 111 and candle 122.

For lead, there is a connection between the detection of lead on the filters from burning and the levels of lead in the wax as well as in the wick. The candles with the highest levels of lead emit lead as particles (detectable). However, lead was not detected on the filter from burning of candle 71 that also has a rather high content of lead amounting to 0.29 mg/kg in the wick of the candle.

For nickel on the filters, there is no clear connection between the concentration in the wicks and the wax, and the filters where nickel was detected. For the the two wicks with the highest content of nickel, candle 6 and candle 111, where up to 2.5 and 1.6 mg nickel/kg wick, respectively, was detected, no nickel was detected on the filters from burning. The reason might be the shown inhomogeneity in the concentrations in the single parts of the candles.

The below bar charts (Figure 18, Figure 19, Figure 20, Figure 21) show the connection between the content of lead and nickel in wax and wicks in the different types of wax. It is obvious that the paraffin candles have the lowest content of lead and nickel in both wax as well as wick, and that the stearin candles contain most nickel in both wax and wick. In addition, it appears that candles made of unknown or mixed wax have most lead in both wax and wick. Table 17 gives an outline of the content analyses and it appears that the content of lead mainly is seen in candles with an unknown type of wax, but there is a high content of lead in the wick from the candle made of fully refined special wax.

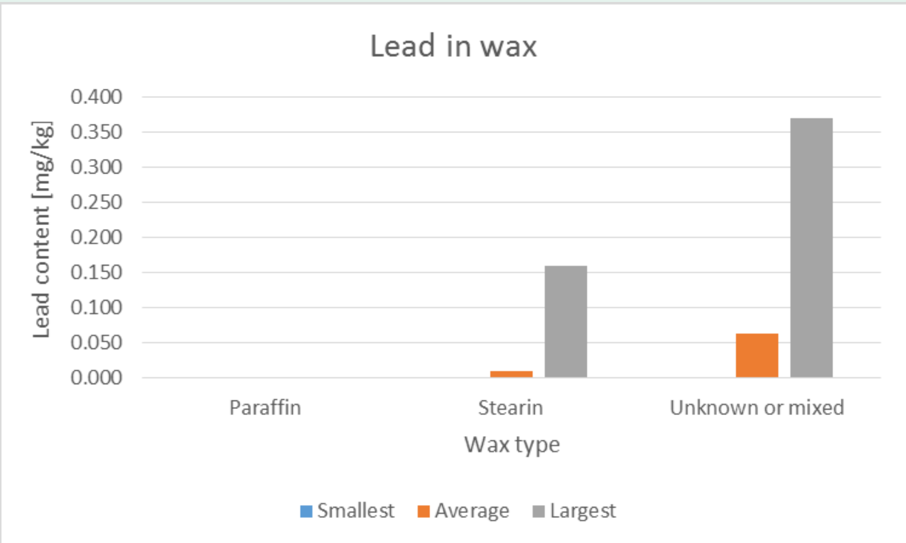

Figure 18
For each of the three main categories of wax type, the smallest, a calculated average and the largest concentration of lead in wax have been stated.
Please note that the smallest concentration is the detection limit of the method, which has been set at the value “0” and therefore it cannot be seen in the diagramme. The detection limits of samples without content are included as “0” in the calculation of the average. The highest value has been used for the double determinations that show results above and under the detection limit, and for the samples where the results of the double determinations vary more than the uncertainty of the method.

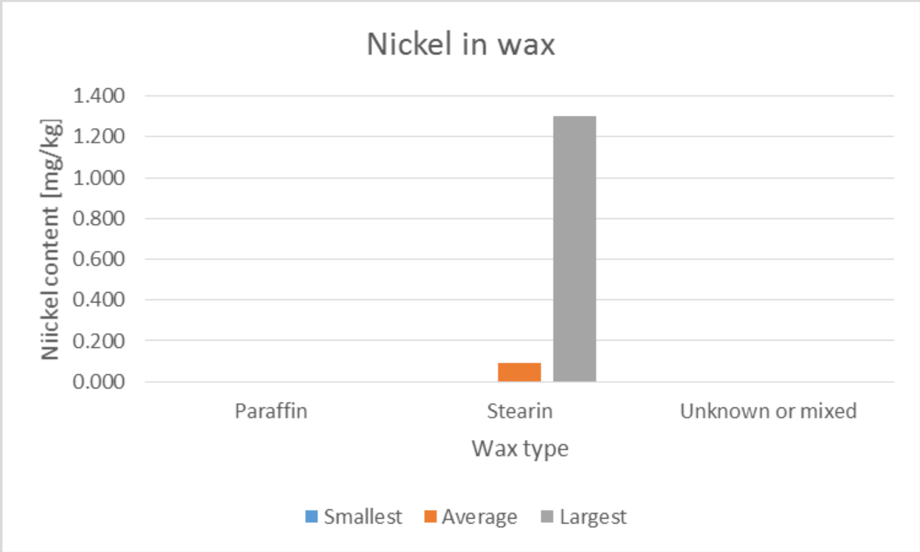

Figure 19
For each of the three main categories of wax type, the smallest, a calculated average and the largest concentration of nickel in wax have been stated.
Please note that the smallest concentration is the detection limit of the method, which has been set at the value "0" and therefore it cannot be seen in the diagramme. The detection limits of samples without content are included as "0" in the calculation of the average. The highest value has been used for the double determinations that show results above and under the detection limit, and for the samples where the results of the double determinations vary more than the uncertainty of the method.

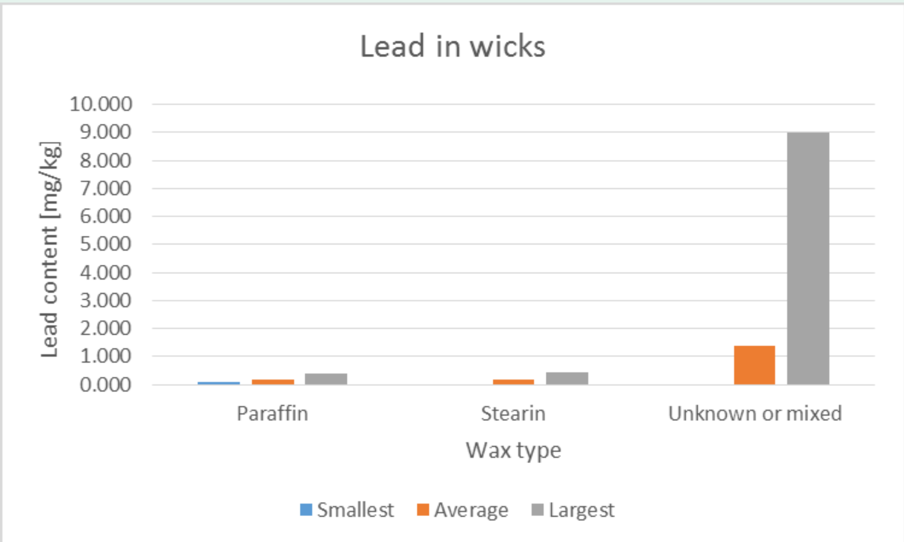

Figure 20
For each of the three main categories of wax type, the smallest, a calculated average and the largest concentration of lead in wicks have been stated.
Please note that the smallest concentration is the detection limit of the method, which has been set at the value "0" and therefore it cannot be seen in the diagramme. The detection limits of samples without content are included as "0" in the calculation of the average. The highest value has been used for the double determinations that show results above and under the detection limit, and for the samples where the results of the double determinations vary more than the uncertainty of the method.

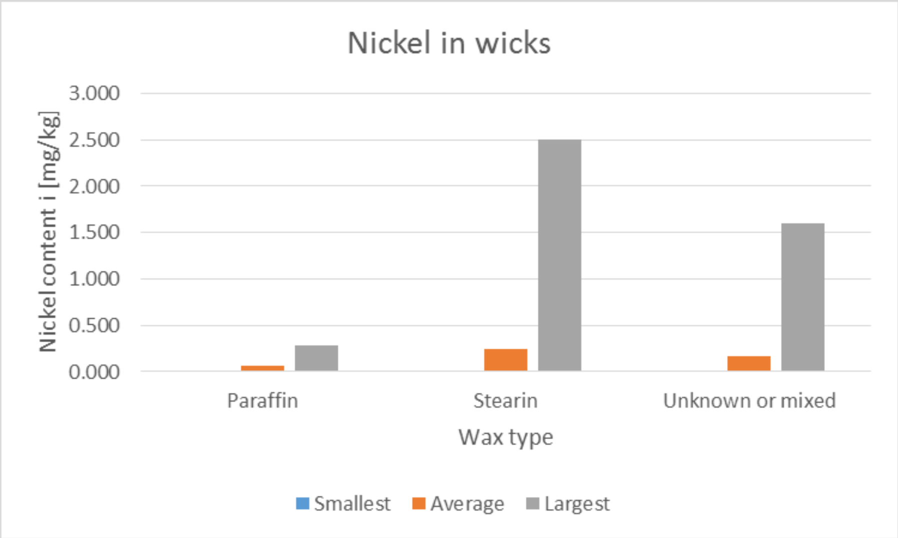

Figure 21
For each of the three main categories of wax type, the smallest, a calculated average and the largest concentration of nickel in wicks have been stated.
Please note that the smallest concentration is the detection limit of the method, which has been set at the value "0" and therefore it cannot be seen in the diagramme. The detection limits of samples without content are included as "0" in the calculation of the average. The highest value has been used for the double determinations that show results above and under the detection limit, and for the samples where the results of the double determinations vary more than the uncertainty of the method.

6.6.4 Assessment of analysis results

In the criterion document for products with the Nordic Ecolabel it appears that lead or nickel must not be used in the production of candles, neither in the wax nor in the wicks. The substances must not be present unless they originate from contamination/impurities from the raw material production. The found levels are assessed to be contamination/impurities from the raw material production of wax and wick[12] , respectively.

According to the Danish Regulation on Lead[13], enclosure 2, candles (tea lights and other candles) must not contain more than 100 mg metallic lead/kg (0.01%). No content was detected in the candles or parts of the candles that exceeds that limit. The highest concentration of lead was found in candle no. 111 that had a content of up to 9 mg/kg in the wick of the candle, and that value is below 10% of the limit value.

There are rules for how much nickel products (intended to come into longer contact with the skin) may emit, but candles do not come within that category of products.
In general, the level of lead and nickel found in wax and wicks must be regarded as low.

The amount of lead and nickel found on the filters in µg/filter cannot be immediately assessed in relation to health effects. The results must be related to the amounts of lead and nickel per cubic metre air to be compared and assessed in relation to acceptance values for air in the indoor environment.

[12] "Contamination comprises residue from the raw material production that forms part of the finished product in concentrations below 100 ppm (0.0100 weight-%, 100 mg/kg), but not as substances that deliberately have been added to a raw material or a product and with a purpose, irrespective of amount. Contamination at raw material level in concentrations exceeding 1.0% in the raw material is considered to be an ingredient. Known decomposed products of ingredients that have a purpose in the product are also regarded to be ingredients". http://www.ecolabel.dk/kriteriedokumenter/088_2_1_KD.pdf , page 10

[13] BEK no. 856 dated 05/09/2009

7. Exposure Scenarios and Risk Assessments

This chapter describes exposure scenarios for users of candles on the basis of the particle level measurements and the metal content of the candles (Chapter 6) and from literature data (Chapter 5). From the health reference values (Chapter 5), risk assessments of the exposure scenarios are made.

The exposure scenarios will include an assessment of the measured parameters from Chapter 6:

- Particle number when burning candles (number of particles/cm^3)
- Particle mass when burning candles (mg/m^3)
- Nickel content in the candles (wax + wick) and in filter samples during burning
- Lead content in the candles and in filter samples during burning

7.1 Exposure scenarios for particle emission

In connection with the establishment of the exposure scenarios, it was decided in the project to develop rather simple and realistic exposure scenarios for users of candles.
To illustrate this, two user scenarios were chosen:

Exposure scenario 1, regular user
This scenario represents the regular user of candles who on weekends (Friday, Saturday and Sunday) burns two candles, eight hours a day. Additionally, this scenario is split into two sub-scenarios, one involving optimal combustion and the other involving sooty combustion.

Exposure scenario 2, major user
This scenario represents the major user of candles who daily and all year around burns 4 candles, eight hours a day. The scenario can be regarded as "worst case". Additionally, this scenario is split into two sub-scenarios, one involving optimal combustion and the other involving sooty combustion. In the sooty combustion sub-scenario it is assumed that two of the four candles are placed in a draughty spot, resulting in sooty combustion, since it is considered unrealistic that all candles would burn with an unsteady, sooting flame.

Sooting combustion has not been investigated in this project, and exposure scenarios involving sooting combustion are therefore evaluated on the basis of Pagels' et al. (2009), which demonstrated major differences in the particle emission, depending on whether the candle burns with a steady non-sooting flame (optimal), or with a sooty and unsteady flame (sooting).

The scenarios are assessed partly for the use of stearin wax candles, partly for the use of paraffin wax candles.

7.1.1 Exposure calculations for particles

The exposure calculations are based upon the particle concentrations measured in the room (cf. Table 14). In this project all of the measurements of particle concentrations in the room were carried out during optimal combustion, and thus provide no information regarding exposure under conditions of non-optimal sooting combustion. Given that sooting combustion has been demonstrated as being a major contributor to particle emissions, the calculated levels of exposure are subsequently compared with data from Pagels' et al. (2009), in which measurements of exposure-related factors were carried out in a test environment by burning four candles simultaneously under optimal and sooting combustion conditions.

Calculated levels of exposure to particles based upon measurements carried out in this project

In Table 18 (below) exposure levels for stearin candles and paraffin candles are presented on the basis of the data presented in Table 14 (section 6.4). The recorded levels shown in Table 14 illustrate emissions when two candles are burned simultaneously in a room 20 m^3 in size, and can thus be directly applied to the exposure scenario involving regular user (scenario 1), and when multiplied by a factor of 2 can be applied to the exposure scenario for a major user, in which four candles are burned (scenario 2). The measurements presented in Table 14 are likewise considered representative of an average usage of eight hours a day. Since sooting combustion was not investigated in this project, exposure is calculated solely for scenarios involving optimal combustion.

Table 18

Exposure scenarios, concentrations with respect to particle number and particle mass (calculated on the basis of values given in Table 14). The cited values indicate the average concentrations for each type of candle as well as the highest recorded level (in brackets).

Scenarios	Particle number (#/cm^3)	Particle mass PM2.5 (mg/m^3)
Stearin candles		
2 candles at optimal combustion	1,6E+06 (1,7E+06)	8,74E-3 (2,0E-2)
4 candles at optimal combustion	3,2E+06 (3,4E+06)	1,74E-2 (4,0E-2)
Paraffin candles		
2 candles at optimal combustion	9,16E+05 (1,3E+06)	5,4E-3 (1,0E-2)
4 candles at optimal combustion	1,8+06 (2,6E+06)	1,08E-2 (2,0E-2)

Comparison with literature data

These calculated levels may be compared to the levels presented by Pagels et al. (2009) (see Table 19), in which measurements were carried out of particle numbers and particle mass during combustion - both optimal combustion and sooty combustion. These measurements were carried out during the simultaneous burning of four white stearin candles and four candles of mixed wax type (a mixture of stearin and paraffin, proportions unknown, coloured) in a climate room 22 m^3 in size with an air change of 0.5 times per hour.

Table 19

Levels of exposure for particle number and particle mass during simultaneous burning of four candles in a climate room 22 m^3 in size (Pagels et al. 2009).
).

Scenarios	Particle number 16-1000 nm [Number/cm^3]	PM* (mg/m^3)
Stearin candles		
4 candles at optimal combustion	1.14E+06	2.1E-01
4 candles at sooting combustion	8.9E+05	6.0E-01
Stearin/Paraffin candles		
4 candles at optimal combustion	5.1E+05	8.6E-02
4 candles at sooting combustion	2.7E+05	1.6

** Stated as the on sum of carbon, organic materials and inorganic materials.*

Particle number

For four candles during optimal burn an exposure level of 3.2E+06 (maximum value 3.4 E+06) particles/cm^3 (for particles 4.4-166 nm in size) can be calculated on the basis of measurements carried out in this project (see Table 18), while Pagels' et al. (2009) measured a level of 1.14E+06 particles/cm^3 (for particles 16-1,000 nm in size) (see Table 19). This is to say that the level measured in this project is approximately three times as high as the level measured in Pagels' et al. (2009) study.

Deviation may derive from the fact that Pagels et al. (2009) did not measure the whole fraction of the ultrafine particles as they used a method that measured in the size range of 16 to 1000 nm. Data from this present project indicate that the ultrafine particles from candles mainly lie in the range of 5-25 nm.

Particle diameter
The measurements carried out in this project indicated an average diameter of particles from stearin candles of 23 (21-29) nm when measured in the room, (see Table 13 and Table 14), which is the same level as the measurements presented by Pagels et al. (2009), who stated the size of the primary particles as 20-30 nm.

Particle mass
For four candles at optimal burn a PM2.5 exposure level of 1.74E-2 (maximum value: 4.0E-2) mg/m^3 (corresponding to 17.4 - 40 µg/m^3) was measured during optimal combustion of stearin candles in this project, whereas Pagels et al. (2009) measured a level of 2.1E-01 mg/ m3 (equivalent to 210 µg/m3), i.e. the assessed exposure level, based on the measurements in this project, is on average 12 times (and at least 5 times) below the level recorded in Pagels' et al. (2009) study.

It is difficult to give a precise explanation of the reasons for the differences between the two studies. However, the deviation may arise from a number of differences in the methodologies applied. Firstly, the sample size differs between the two studies. Pagels et al. measured only the emission form one type of stearin candle and one type of mixed stearin/paraffin candle, while the present project measures seven different stearin candles and five different paraffin candles, thereby ensuring a greater degree of reliability. Secondly, the setup of the respective tests differs, in that Pagels et al. uses an oscillating fan for agitating the air, whilst the present project does not. As Pagels et al. demonstrates that non-optimal combustion has a major influence on PM, it could be expected that even a small degree of non-optimal combustion can influence the result. Lastly, another crucial difference is that, in the present project, particle mass is measured by means of DustTrak, while Pagels et al. measures particulate matter via collection in filters. The outcome calls into question how suitable DustTrak DXR is for measurement of particulate matter from candles burned under optimal conditions. The particle mass measured is close to the methodology's detection limit of 0.001 mg/m^3, and all candles primarily emitted particles which in terms of size fell outside of the methodology's detectable range (a DustTrak detects particles in the range 100 nm to 15 μm). It is therefore assessed that measurements conducted using DustTrak may underestimate the level of particulate matter in the room.

Conclusion on exposure levels for particles
Overall, the measured particle massin the study by Pagels et al. (2009), which targeted an exposure assessment, are considered to better reflect a user's exposure to candles than the use of emission data measured in this project, where the measurements of particulate matter are carried out by means of DustTrak and the candles are studied during optimal combustion. Nevertheless, results from both studies have been incorporated into the risk assessment.

Calculated levels of exposure to particles based upon literature data (Pagels et al.)
In Table 20 the exposure levels for the different user scenarios are reassessed based on data from Pagels et al. (2009) shown in Table 19. By the calculation of scenarios for the regular user (scenario with two candles), the values from Pagels et al. are used multiplied by a factor of 0.5, as Pagels et al. use four candles in all their setups. The starting point of the scenario is a room volume of 22 m^3 and an air exchange rate of 0.5 times per hour corresponding to the circumstances used in the study by Pagels et al..

Table 20
Overview of exposure scenarios with indication of concentrations of particle number and particle mass concentrations (based on data in Pagels et al. (2009)).

Scenarios	Particle number 8h (#/cm^3)	Particle mass PM2.5 8h (mg/m^3)
Stearin candles		
2 candles optimal burn	5.52E+05	1.07E-01
2 candles sooting burn	4.45E+05	3.02E-01
4 candles optimal burn	1.14E+06	2.14E-01
2 candles optimal + 2 candles sooting	9.97E+05	4.09E-01
Stearin/paraffin candles (blue candle)		
2 candles optimal burn	2,55E+05	4,3E-02
2 candles sooting burn	1,35E+05	8,02E-01
4 candles optimal burn	5.1E+05	8,6E-02
2 candles optimal + 2 candles sooting	3,9E+05	8,45E-01

7.1.2 Risk assessment of scenarios for particle emission

As indicated in chapter 5.4, sufficient knowledge has not yet been established to assess the potential risk and health effects of particles emitted from burning candles.

To make a preliminary assessment, the average levels of particle mass, expressed as PM2.5, can be compared with the limit values for PM2.5 in outdoor air, as these limit values for particle mass apply to outdoor air particles in general, regardless of their chemical composition. There are no corresponding limit values for the particle *number concentration* in outdoor air that can be used.

On the other hand, there are health-based values in outdoor air for specific components, such as lead and nickel, to which emissions from candles can also be compared.

Table 21 indicates the limit values relevant for this project.

Table 21
EU limit values and WHO guideline values for selected air pollution components in outdoor air.

Pollution component	EU value Dir 2008/50/EC	WHO values
PM2.5	0.025 mg/m3 (per 2010) 0.020 mg/m3 (per 2020) Annual values*	0.010 mg/m3 annual value 0.025 mg/m3 24-hour value** (WHO, 2006)
Lead	0.5 µg/m3 Annual value	0.5 µg/m3 Annual value (WHO, 2000)
Nickel	20 ng/m3 Annual value	2,5 ng/m3 25 ng/m3 250 ng/m3 (WHO, 2000)***

** Average level of 24-hour values over a year.*
*** Measured average level over 24 hours.*
**** The three indicated levels correspond to increased lifetime risk of developing cancer of 10^{-6}; 10^{-5} and 10^{-4}, respectively.*

7.1.3 Risk assessment of particle exposure

In Table 22, the exposure levels of the eight sub-scenarios from Table 18 and Tabel 20 have been modified and recalculated as average exposure levels over 24 hours and over a whole year in order to compare with the limit values in Table 21.

Table 22
Overview of exposure scenarios, particle number and particle mass concentrations.

Scenarios	Particle no. con.	Particle mass, PM2.5		
		Average *		
		8 hours	24 hours	Year
	[number/ cm^3]	[mg/m^3]	[mg/m^3]	[mg/m^3]
Stearin candles (This project)**				
2 candles optimal burn, (8h, 3d/week)	1,6E+06	0,0087	0,0029	0,0012
	(1,7E+06)	(0,02)	(0,0067)	(0,0029)
4 candles optimal burn, (8h, 365d/year)	3,2E+06	0,0174	0,0058	0,0058
	(3,4E+06)	(0,04)	(0,013)	(**0,013**)
Paraffin candles (This project)**				
2 candles optimal burn, (8h, 3d/week)	9,16E+05	0,0054	0,0018	0,0008
	(1,3E+06)	(0,01)	(0,0033)	(0,0014)
4 candles optimal burn, (8h, 365d/year)	1,83E+06	0,0108	0,0036	0,0036
	(2,6E+06)	(0,02)	(0,0067)	(0,0067)
Stearin candles (Pagels at al.)				
2 candles optimal burn, (8h, 3d/week)	5.52E+05	0.107	**0.036**	**0.015**
2 candles sooting burn, (8h, 3d/week)	4.45E+05	0.302	**0.101**	**0.043**●
4 candles optimal burn, (8h, 365d/year)	1.14E+06	0.214	**0.071**	**0.071**●
2 candles optimal + 2 candles sooting, (8h, 365d/year)	9.97+E05	0.409	**0.136**	**0.136**●
Stearin/paraffin candles (blue candle, Pagels et al.)				
2 candles optimal burn, (8h, 3d/ week)	2,55E+05	0,043	0.014	0.006
2 candles sooting burn, (8h, 3d/ week)	1,35E+05	0,802	**0.267**	**0.115**●
4 candles optimal burn, (8h, 365d/year)	5.1E+05	0,086	**0.029**	**0.029**●
2 candles optimal + 2 candles sooting, (8h, 365d/year)	3,9E+05	0,845	**0.282**	**0.282**●

** Compared to the 8-hour PM2.5 values, the 24-hour average has been calculated by adjusting with the factor 8h/24h = 1/3, while the annual values for the weekend scenarios (3d/week) have been further corrected with 3d/7d = 3/7.*
*** The calculated exposurescenaries are shown as mean of tested candles and I parentes the result from thecandle with the highest emission.*

Particle mass concentration

When the obtained exposure levels in the columns for average 24-hour exposure and average annual exposure are compared with the corresponding health-based limit values, it can be seen that all values in bold exceed the WHO recommended limit values in outdoor air (2006) (either 0.025 mg/m^3 as a 24-hour value or 0.010 mg/m^3 as an annual value), while the ●-marked values also exceed the EU annual value of 0.025 mg/m^3.

The values that exceed the WHO values, where mostly derived from the study of Pagels et al., only the one candle with the higesth PM2.5 emission from this study exceeded the WHO annual value.

The largest excess achieved in relation to the WHO annual value of 0.010 mg/m^3, which exceeded the value by up to 28 times, was seen for the worst-case scenario with the four stearin/paraffin candles tested by Pagels et al., of which two are sooting.

It is not possible directly to transfer outdoor air limit values to indoor air and to the emission from candles. It can only be seen as a first indication that harmful effects might appear particularly in connection with the exposure scenarios that have a large consumption of candles and/or in relation to sooting burning conditions.

EU and WHO values are based on well-documented dose-response relationships regarding increased mortality in the population due to particles in outdoor air, when especially combustion particles are considered to be of great importance. However, it is not considered justifiable to use these specific dose-response relationships in connection with a risk assessment of particles from candles, as knowledge about the effect of these particles is still very limited, and as the combustion particles from candles have a different chemical composition than the combustion particles in outdoor air.

Particle number concentrations
As for the particle number, the exposure in Table 22 corresponds to the homes with highest exposure levels described in Bekö et al. (2013), in which up to 2.5 x 10^5 particles/cm^3 (particle size 10-300 nm) in average over 24 hours were measured.

It should be noted that the primary particles from the candles are very small (about 5-30 nm) and that these particles if deposited in the airways mainly will be deposited in the bronchioles and the alveoli (Figure 3), from where the insoluble parts of the particle are eliminated very slowly (months to years). The deposition and the possible accumulation in the terminal airways provide optimal conditions for induction of adverse health effects.

Especially under sooting conditions, larger particles occur, mainly due to agglomeration of the primary particles. During sooty burning of the candles, Pagels et al. (2009) found a very small impact on the number concentrations of the small primary particles in the air, while the particle mass increased significantly as a result of several large agglomerates of particles consisting mainly of carbon with an overall particle size of 270 nm. Particles of this size are deposited to a lesser extent (measured by number) in the airways than primary particles (see Figure 3) and will therefore be removed from the lungs more quickly (hours to days), but the particles that are deposited contain many primary particles. The results in this project confirm that particles from candles agglomerate after emission. Furthermore the results show that particles from stearin candles aggolerate to a higher degree than particles from paraffin candles (see section 6.4). One explanation for this could be that particles from stearin acid compounds have a higher polarity, than the particles emitted from paraffin. Another possibility is that stearin candles produce more water vapour than paraffin candle and that the higher humidity can contribute to the agglomeration.

As mentioned earlier, the amount of available data that can be used to assess the health effects related to particle number concentrations is very limited, and currently no limit values have been established to which the exposure levels above can be compared. Based on recent data obtained in connection with the Danish CISBO project (Chapter 5.4.2.3), it would be expected that even short-term exposure to elevated levels of particle number concentrations may have the potential to adversely affect the lung systems and the cardiovascular system.

As shown in Table 15, stearin wax candles on average emit more particles than paraffin wax candles as well as a slightly larger particle mass. However, it is very uncertain on that basis to conclude that stearin candles are more harmful than paraffin candles, as that would require more knowledge about the particle composition. Particles with high carbon content, for example, must be considered more critical to health than particles consisting of soluble salts. However, apart from nickel and lead the chemical composition of the emission from stearin and paraffin candles has not been further examined in this project.

Overall, the burning circumstances are assessed to be much more important than whether the candle is made of stearin or paraffin, as a candle burning with a sooting flame leads to significantly increased particle levels and carbon levels in the air, which must be considered to be of particular health concern.

7.2 Exposure scenarios for lead and nickel

7.2.1 Lead and nickel content in candles

The content of lead and nickel was measured in wax from the candles and the wicks. From Table 17, where these data are stated, the candles with the most significant concentrations of lead and nickel were identified.

Table 23
Candles with the highest contents of lead and nickel.

	Wax, metal content Conc. [µg/g]	Wick, metal content Conc. [µg/g]
Candle no. 87	0.28 lead	0,37 lead
Candle no. 111	0.11 lead	9.0 lead
Candle no. 5	<0.05 nickel	0.69 nickel
Candle no. 44	1.3 nickel	0.09 nickel

This content of metals could only be found to some extent in the soot of the candles deposited on the filters placed above the candles (see Figure 5 and Table 16). From candle no. 87, lead could not be detected in the filter (<0.05 µg lead/ filter), while candle no. 111 deposited 0.6 µg lead on the filter. From candle no. 44, nickel could not be detected on the filter (<0.05 µg nickel/ filter), while candle no. 5 deposited 0.17 µg nickel on the filter.

On this basis, candle no. 111 for the assessment of exposure to lead and candle no. 5 for the assessment of exposure to nickel were selected for the exposure assessments, because for these candles it has been shown that the metal content of the candles is also reflected in the content of the emitted combustion particles.

7.2.1.1 Emission rate of nickel and lead

In a previous Danish EPA report, an exposure assessment for lead and nickel was made in connection with the burning of candles (Danish EPA 2002). The exposure assessment was performed by first of all estimating the emission rate (source strength) based on the metal content in the wax and the wick:

$$Emis.\ rate\ (\mu g/h) = \frac{weight\ of\ wax\ (g)}{burning\ time\ (h)}\ x\ Conc\ in\ wax + \frac{weight\ of\ wick\ (g)}{burning\ time\ (h)}\ x\ Conc\ in\ wick$$

By using this method of calculation, it is assumed that the entire content of lead and nickel in the candles is recovered in the emitted particles.

Emission of lead, candle no. 111

The burning rate of candle no. 111 was in a subsequent test measured to 6.86 grams per hour. Of this mass, 99.2% is assessed to consist of wax and 0.8% of the wick (data on this weight distribution is from Danish EPA (2002), where this ratio was found in a similar type of candle).

Emiss. candle no. 111 (µg lead/h) = 6.8 g/h x 0.11 µg/g+ 0.06 g/h x 9 µg/g

Emiss. candle no. 111 (µg lead/h) = 0.75 µg/h+0.54 µg/h = 1.3 µg lead/h

Emission of nickel, candle no. 5

In a subsequent test, the burning rate of candle no. 5 was measured to 9.1 grams per hour.

Using a similar distribution of weight between wax and wick, the emission rate is calculated:

Emiss. candle no. 5 (µg nickel/h) = 9.0 g/h x 0.025 µg/g+ 0.07 g/h x 0.69 µg/g

Emiss. candle no. 5 (µg nickel/h) = 0.225 µg/h+0.048 µg/h = 0.27µg nickel/h

In the calculations, the nickel content of the wax was set at 50% of the detection limit, as nickel could not be detected in the wax.

7.2.2 Exposure levels, metal content

For the calculation of the maximum achievable levels in a room, the following context is used:

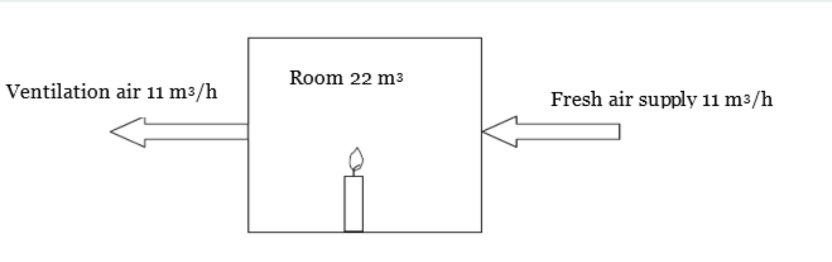

Figure 22
Box model used for calculating the air concentration in a room with an air exchange rate of 0.5 times per hour.

When a candle burns, the concentration of pollution will gradually grow until a steady state condition is reached where the burning candle emits the same amount of substance to the air as is vented out by the air exchange. The increase in pollution level and achievement of a steady-state situation is illustrated in Figure 23.

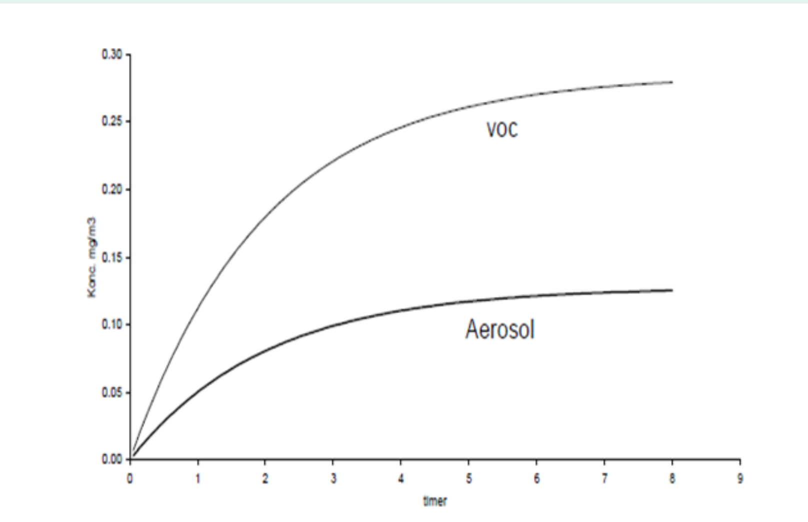

Figure 23
Theoretical development of air concentrations of aerosols (particles) and VOCs in rooms with an air exchange rate of 0.5 times per hour (from the Danish EPA, 2002).

When the concentration in the ventilation is in equilibrium with the emitted amount from the candle, the room concentration can be calculated from the following expression:

$$C_M = \frac{E_c}{V \cdot n}$$

Where
C_M: air concentration of a chemical in room air (µg/m^3)
E_C: emission rate of the substance (mg/h)
V: room volume (m^3). Here set to 22 m^3 *
n: air exchange rate of the room (t-1). Here set to 0.5 h^{-1} *

** The same values, which underlie the exposure assessments of the particle levels in Table 22, were chosen.*

As stated in Danish EPA (2002), the room concentrations will gradually approach the upper theoretical maximum value after a certain number of hours as shown in Figure 23.
The average exposure after eight hours of burning of candles will be somewhat below the theoretical maximum value as the exposure level is gradually built up. However, remaining in the room after the candle has been put out will result in continuous exposure that now gradually will decrease, and therefore it seems reasonable to assess the exposure of eight hours of burning as equal to stay at the theoretical maximum value. The average daily exposure will correspond to 8h/24h = 1/3 of the assessed 8-hour value.

Exposure level lead
In the scenario with two and four candles, respectively, the following theoretical room concentrations of lead can be calculated:

$$\mathrm{C_{lead}(2\ candles)} = \frac{\mathrm{2\ x\ 1.3\ \mu g\ lead/h}}{\mathrm{22m3 \cdot 0.5\ /h}} = 0.24\ \mu g\ lead/m^3$$

$$\mathrm{C_{lead}(4\ candles)} = \frac{\mathrm{4\ x\ 1.3\ \mu g\ bly/h}}{\mathrm{22m3 \cdot 0.5\ /h}} = 0.47\ \mu g\ lead/m^3$$

Exposure level nickel
Similarly, for nickel can be calculated:

$$\mathrm{C_{nickel}(2\ candles)} = \frac{\mathrm{2\ x\ 0.27\ \mu g\ nickel/h}}{\mathrm{22m3 \cdot 0.5\ /h}}\ 0.05\ \mu g\ nickel/m^3$$

$$\mathrm{C_{nickel}(4\ candles)} = \frac{\mathrm{4\ x\ 0.27\ \mu g\ nickel/h}}{\mathrm{22m3 \cdot 0.5\ /h}}\ 0.10\ \mu g\ nickel/m^3$$

7.2.3 Risk assessment of exposure to lead and nickel

For the risk assessment of lead and nickel, it can be seen that the limit values to which the exposure should be compared, are average daily values over one year, i.e., an annual average (for EU limit values in outdoor air 0.5 µg/m^3 for lead and 0.020 µg/m^3 for nickel, respectively).

Below, the exposure in connection with the burning of candles for eight hours is converted to annual values for the selected scenarios. Please note that these scenarios do not distinguish between a sooting and a non-sooting burn, as there are no data for the burning rate of the candles during sooty burning.

Table 24
Overview of exposure scenarios for lead and nickel.

Scenarios	Metal conc. 8-hour average [µg/m³]	Metal conc. Annual average [µg/m³]
Lead (candle no. 111)		
2 candles optimal burn (8h, 3d/week)	0.24	0.034
4 candles optimal burn (8h, 365d/year)	0.47	0.157
Nickel (candle no. 5)		
2 candles optimal burn (8h, 3d/week)	0.05	0.007
4 candles optimal burn (8h, 365d/year)	0.10	**0.033**

** Compared to the 8-hour values, the annual averages are calculated by correcting with the factor 8h/24h = 1/3 for the daily scenarios, while the weekend scenarios (3d/week) are further corrected with 3d/7d = 3/7.*

It can be seen that the scenario in which four candles are used every day for eight hours theoretically may cause the air concentrations of nickel to exceed the limit value for nickel. It should be emphasised that these calculations are made from theoretical worst-case considerations, where it is assumed that total metal content in the candles is emitted into the air and that the particles are only eliminated from the air during air exchange in the room (i.e., no sedimentation of the particles or adhesion to the surfaces of the room and the furniture). Finally, the level of exposure to nickel would only be 17% of the level calculated in Table 24, when assuming that there was no nickel in the wax, rather than using a nickel content of 50% of the detection limit in the calculations.

So even if this theoretical nickel scenario shows that the limits for nickel are exceeded, this is very uncertain and only due to a series of worst case assumptions. Whether the risk is present in practice can only be resolved by follow-up measurements regarding the emission rate of nickel from the candles or by measurements in a model chamber test, where the test design is targeted at the exposure assessment for users.

There are no specific regulatory limit values for the content of metals in candles. For lead in articles, the Danish Regulation on Lead has established a maximum content of 100 mg lead/kg. Based on the above calculations, where the lead content in the measured candles was significantly lower than this limit value, the limit value is assessed to be too high to ensure that the indoor environment does not exceed the EU limit value in air of 0.5 µg lead/m^3.

8. Assessment and Discussion

8.1 Discussion

The objective of this project was to obtain more knowlegde of the particle pollution that is emitted when burning candlestick candles. In order to obtain a broad coverage of the subject, 32 white candles for candlesticks were selected. They had been identified in different stores and retail chains that i.a. sell candles to ordinary consumers.

The measurements in this project were carried out on 32 different white candlestick candles of varying height (between 14-40 cm), but with a rather similar diameter of 20-24 mm. The selection of the 32 white candlestick candles constitutes a broad selection distributed on price (DKK 1.20-25.00/each), brand, country of origin (mainly Denmark/EU/the Baltic states, but also China), the Nordic Ecolabel/no Nordic Ecolabel, and the wax type (stearin, paraffin, mixed products and unknown [not informed] wax types), see Table 10.

In the course of the project, the particle emission from candlestick candles was measured under optimum, steady burning conditions just above the flame and in a standard room of 20 m^3. No measurements were carried out on sooting candles or during smouldering (when putting out the candle).

The measured values for PM2.5 in this project were in general very low compared to what was expected, cf. literature. That is probably the case, as the set-up used in this project to burn candles has given optimal burning conditions. Therefore, no influence from draught or the like was found that could have caused sooting – the main reason for PM2.5.

It has not been possible to find sufficient information about the wick types in the different candles to carry out a study regarding the influence of the wick on the particle emission.

The wax type of the selected candles were mainly stearin (app. 1/3 of the candles), *Unknown* wax type (app. 1/3 of the candles) and paraffin and mixed candles. In the project, it was chosen to categorise the wax types in stearin (16 candles), paraffin (5 candles) and *Unknown*/mixed candles (11 candles). On that basis, a comparison of the wax types could be carried out.

App. 90% of the candles sold in Denmark in 2014 were white candles for candlesticks. Therefore, tea lights, square pillar candles and oil candles were not investigated in this study and neither were scented candles, dyed candles, birthday candles and "seasonal candles" (Christmas tree, Easter and calendar candles). To which extent data from this project is representative for other candles of a different design and composition is uncertain.

Measurement results

Candles made of stearin show a clear tendency to emit more particles than candles made of paraffin. From an average consideration, a stearin candle emits 19 million particles/cm^3, whereas a paraffin candle emits 7.8 million particles/cm^3, as measured at the source, resulting in room concentrations measured as 1.6 million paticles/cm^3 and 0.92 million paticles/cm^3. The group called *Unknown wax type/mixed products* is situated between stearin and paraffin, which intuitively makes sense if it is assumed that the mixed products are candles with a content of stearin as well as paraffin.

The candle that clearly emitted fewest particles was a paraffin candle. The candle emitted $1.9 \cdot 10^5$ particles/cm^3 (190,000/cm^3), which is 42 times fewer particles than the average of paraffin candles, and 103 times fewer particles than the average of stearin candles.

Opposite, the candle that emitted most particles was a stearin candle that emitted $3.2 \cdot 10^7$ particles/cm³ (32 million/cm³), which is twice as many as the average of stearin candles and four times as much as the average of paraffin candles.

The variations within each wax type are different, but they partly reflect their max. and min. particle emissions. As measured just above the flame, the emission from burning paraffin candles varies 84 times between the candle that emits fewest particles and the candle that emits most particles. For stearin, the variation is nine times between the lowest and highest emission, whereas the emission from the *Unknown* wax type varies 23 times. That should be seen in relation to the max. particle emission for paraffin being $1.6 \cdot 10^7$ particles/cm³ (16 million/cm³), whereas the max. emission from stearin is $3.2 \cdot 10^7$ particles/cm³ (32 million/cm³). The variation within each wax type therefore covers large differences between the candles that emit fewest and most particles, respectively, of each wax type. Therefore, the study shows that the paraffin candles have a more variation regarding emission of particles compared to stearin candles, even though the emission in general is lower for paraffin candles.

The size of the measured, emitted particles (average particle diameter) has a rather narrow interval from 7-18 nm. Assessed from the average particle diameter, there is no great difference whether particles are emitted from a stearin candle (13 nm), from a paraffin candle (12 nm) or from one of the candles made of *Unknown* material (11 nm), as measured just above the flame. By measuring the particle size in a room with lit candles, it was found that the particle size increased to an average of 17 nm for paraffin candles and to 23 nm for stearin candles. The findings indicate that the paticles agglomerate after emission to the inddor air.

Regarding the emission of particle mass, which in literature is regarded to be the parameter that is closest connected to health hazardous effects from particles, stearin candles in average emit sligthly more particle mass than paraffin candles. In average, the particle mass emission for stearin candles is 4.6 µg/m³ and 4.4 µg/m³, as measured as source and room concentrations respectively, whereas it was measured to 3.9 µg/m³ and 2.7 µg/m³ for paraffin candles. As in the case of particle number, the variation between highest emission and lowest emission within the wax types is highest for paraffin (47 times), whereas it is 22 times for stearin, as measured as source concnetrations just above the flame. The mixed products/*Unknown* only vary seven times between the highest and lowest emission, which reflects that the minimum emission of particle mass for this group is somewhat higher than for stearin and paraffin.

The above applies to the candles when they are burning with a steady flame, meaning under optimal conditions.

However, the variations between the candle types are overshadowed by the burning conditions. A candle with a sooting flame (e.g., when burning in a draught, when burning with too long a wick or when the candle does not burn evenly) will have considerable influence on the particle amount that is emitted as sooty particles (with a particle diameter of around 270 nm). Literature has shown that candles with a sooty burn emit up to 29 times larger particle mass than during optimal burning conditions. On the other hand, the emission of ultrafine particles (particles under 100 nm) is only influenced to a smaller degree by the burning conditions.

Health aspects
For both exposure scenarios, i.e., for a regular user of candles (two candles lit three times a week) and for a major user (four candles lit each day) it was found that exposure in both cases significantly exceed both the WHO and the EU health-based limit values for particles in the outdoor air.

It is well-known that particles in the outdoor air may cause serious adverse health effects. Most significant is the increased mortality rate in the population of 6% at an increase of 10 µg/m^3 of the annual PM2.5 level in ambient air level. Compared to this, the high particle levels from burning candles must give rise to concern, as the additional particle exposure might be expected to cause increased incidence of respiratory diseases and cardiovascular diseases.

The amount of available data that can be used to assess the adverse health effects related to the increased particle number concentrations caused by burning candles is very limited. Currently, no relevant limit values have been established to which the increased particle number concentrations can be compared.

In average, stearin wax candles emit higher amounts of particles than paraffin wax candles, and also a slightly larger particle mass. However, it is very uncertain on that basis to conclude that the stearin wax candles can be considered more harmful than the paraffin wax candles, as that would require more knowledge about the chemical composition of the particles. Particles with high carbon content, for example, must be considered more critical to health than particles consisting of soluble salts. However, apart from nickel and lead the chemical composition of the emission from stearin and paraffin candles has not been further examined in this project. Overall, the burning conditions are assessed to be much more important than whether the candle is made of stearin or paraffin, as a candle burning with a sooting flame leads to significantly increased particle levels and carbon levels in the air, which must be considered to be of particular health concern.

In spite of the detection of metals in 26 of 32 candles, the measured levels of lead and nickel in the candles in this study are very low and not considered to be of any health concern.

8.2 Uncertainties and limitations

This study was performed on very comparable white stearin wax candles and paraffin wax candles of relatively uniform dimensions. It is therefore unclear to which extent the data obtained for these candles is representative for other candles, e.g., coloured candles; candles of other dimensions, composition and design. For all types of candles, it must be expected that the emission of particles measured as particle mass will be significantly higher if they burn with sooting flames under non-optimal burning conditions.

However, different burning conditions were not the objective of this project where the primary objective was to measure the emission differences between white candles consisting of various waxes. Data exploring the impact of optimal verus non optimal burning condition are therefore achieved from the literature and not verified in this study.

Based on the lack of knowledge concerning the health effects of particles from candles, it has not been possible to make a more accurate assessment of the described scenarios. Although comparison to ambient air particles can be made, there is insufficient evidence to apply the dose-response relationships for health effects known from ambient air.

Regarding assessment of the metal exposure scenarios, it must be emphasised that very large uncertainties pertain to the exposure assessments, as it is very uncertain to which extent the metal content in wax and wick also will be reflected in the metal content of the emitted particles.

8.3 Improving knowledge

The following aspects are assessed to be essential to achieve increased knowledge regarding emission, exposure and health implication in relation to the use of candles:

Emission

- Further chemical analysis of emitted particles and their composition would form a better basis for assessment of health impact from inhalation of the particles.

- Further knowledge regarding the importance of non-optimal burning, i.e., measurement of particle emissions by sooting and during the smouldering phase.
- Further knowledge on how the dimension and design of the candles effect the emissions in terms of: PM2.5, carbon (EC), number of particles (UFP), PAH, lead and nickel.

Exposure
- Further systematic measurements in test chambers with regard to the assessment of the exposure to: PM2.5, carbon (EC), number of particles (UFP), PAHs, lead and nickel - both during optimal and sooty burning.

Hazard and safety assessment
- Additional data basis for assessing health effects of ultrafine particles/particle number concentrations of candles.
- Further toxicological testing of particles from candles in terms of effects and comparability with other particles, such as outdoor air particles, diesel particles, etc.
- Additional data basis from population surveys with sub-groups with high consumption of candles in terms of health effects.
- Detailed analyses to assess whether the dose-response relationships from particles in the outdoor air can be applied to particle exposure from candles.

8.4 Conclusion

Measurements of a total of 64 candles in this project have shown that white stearin candlestick candles in general emit twice as many ultrafine particles as white paraffin candlestick candles.

Based on the measured source concentration candle 127, made of paraffin, was the candle that emitted fewest particles (less than 200,000 particles/cm³). The candle is a rather expensive candle (DKK 10), it comes from an unknown country of origin, and does not have the Nordic Ecolabel.

The three candles that emitted most particles are made of stearin (candle no. 5, 45 and 100). These three candles all emitted more than 25 million particles/cm³. Candle no. 5 is made in Sweden and is the least expensive candle that was purchased out of the 32 different candles that were tested. Candles no. 45 and 100 both come from an unknown country of origin and pricewise they are in the low end (less than DKK 5 per candle). None of the candles have the Nordic Ecolabel.

Candle 87 emitted most particle mass (more than 12 µg/m³). The wax type and the country of origin of the candle are *Unknown* and it costs DKK 8/each. Then follow candles no. 101 and 102, both made of stearin and both of unknown country of origin. The prices are app. DKK 7/each and DKK 11/each, respectively, so both are in the high end. None of the candles have the Nordic Ecolabel.

Lead was detected in 26 out of the 32 different wicks, and lead was detected in six of the analysed waxes. The six candles where no lead was detected in the wick cost from DKK 5/each to DKK 25/each. None of the candles have the Nordic Ecolabel (paraffin cannot achieve the Nordic Ecolabel).

No lead was detected in the known paraffin candles (meaning that in the candles with a known wax type stated to be paraffin, no lead was detected. The price of the five paraffin candles varies from DKK 2.5/each to DKK 15/each. Three of the six candles with a lead content in the wax are made of stearin and the other three are of the wax type *Unknown.*

It has been detected that candles with a content of lead in wax and wicks also have a lead content in the emitted particles that were sampled when burning the candle. That means that if candlestick candles with a content of lead in wax and wick are burned, then the lead can be detected again in the emitted particles, and therefore they constitute a potential health risk when inhaled.

In nine of the candles, nickel was detected in the wicks (three of them had the Nordic Ecolabel), and two of the nine candles also have an analysable content of nickel in the wax. The two candles with a content of nickel in the wax are both made of stearin (and also contain lead in the wax). The two candles cost DKK 2.5 and DKK 5, respectively. The price of all of candles with a content of nickel in the wicks varies between DKK 1.2 and DKK 5 for eight of the candles and the last candle costs DKK 10.

When performing consumer exposure scenarios and risk assessments to emissions from candle burning, it is especially the increased particle exposure in terms of particle mass (PM2.5) that gives rise to health concern. Thus, for both the regular use scenario of candles and the major use scenario, significant exceedances of the WHO and EU limit values for PM2.5 in outdoor air are calculated.

Although the outdoor air limit values cannot be directly transferred to indoor air, and thus the emission from candles, this is an indication that negative health effects may be a result of particle emissions from candles in the described scenarios. Especially scenarios with high consumption of candles and/or sooty burning may cause very high particle exposures. Therefore, it can be expected that the additional particle exposure to PM2.5 may cause increased incidence or exacerbation of respiratory diseases and cardiovascular diseases.

The amount of available data that can be used to assess adverse health effects related to the increased particle *number* concentrations of particles in the air is very limited, and currently no limit values have been established to which the exposure levels can be compared. However, based on recent data obtained in connection with the Danish CISBO project, it would be expected that even short-term exposure to elevated levels of the particle number may have a negative impact on the lungs and the cardiovascular system.

Because of the lack of knowledge regarding the composition of candle particles, it is difficult to indicate whether stearin wax candles emitting increased levels of particles (both particle mass and particle number) constitute a greater health risk than paraffin wax candles. However, the burning conditions are considered very crucial, as candles burning with a sooty flame (e.g., due to a draught or too long wick) cause a significantly increased PM2.5 level and carbon level in the air.

In order to avoid possible harmful effects of the use of candles, it can therefore be advised to make sure that the candles burn with a steady and non-sooting flame. This will reduce the exposure to particle mass (PM2.5) and carbon significantly.

As mentioned, the measurements in this project show that paraffin wax candles in average emit about half the number of ultrafine particles and a lower particle mass than stearin wax candles when burning under optimal conditions. However, there is too much variation and uncertiency to conclude that stearin candles must be considered more harmful than paraffin candles, since that would require more knowledge of the particle composition. Also the burning conditions are assessed to more important than the type of wax.

So, from a health perspective, (whether this is stearin wax or paraffin wax candles) highest priority should be given to selecting candles of a quality that burn with a steady and non-sooting flame.

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Bilag 1. Questionnaire

TEKNOLOGISK INSTITUT

Levende stagelys

Spørgsmålene omhandler alene stagelys (diameter 20-27 mm)

På vegne af Miljøstyrelsen er Teknologisk Institut i samarbejde med DHI i gang med at kortlægge markedet for levende stagelys i Danmark.

I kortlægningen er der fokus på stagelys og specielt deres udledning af partikler og visse tungmetaller ved afbrænding. I den forbindelse vil vi gerne have yderligere oplysninger om stagelysene, som kan købes på det danske marked. Indledningsvis vil vi dog gerne have jer til at oplyse de tre lystyper, I sælger flest af.

Vi vil bede jer besvare alle de spørgsmål, I kan, så godt som muligt.

Skulle der være spørgsmål til ovenstående, er I meget velkomne til at kontakte os.

Christian Fischer, telefon 72 20 25 85, e-mail chfi@teknologisk.dk
Peter Bøgh Pedersen, telefon 72 20 26 40, e-mail pbbp@teknologisk.dk

*Vi vil sætte pris på, at I svarer hurtigt tilbage, og vi vil tillade os at kontakte jer, hvis ikke vi har hørt fra jer **inden d. 13. april 2015**. Returneres til: pbbp@teknologisk.dk.*

Dato:
Virksomhed:

Spørgsmål 1
Nævn de tre typer af lys i prioriteret rækkefølge, som I sælger flest af: (fx fyrfad, stagelys, bloklys, olielys, kertelys, duftlys, flydelys, ...)
1:
2:
3:

Spørgsmål 2
Hvor mange stagelys sælger I om året?

TEKNOLOGISK
INSTITUT

Spørgsmål 3
Hvor stor andel udgør stagelys af jeres samlede salg af levende lys? Angiv gerne total antal stagelys ud af total antal samlede levende lys: Angiv alternativt andel i procent:
Spørgsmål 4
Hvor stor andel af jeres samlede salg af stagelys udgøres af *hvide* (ufarvede) stagelys? Angiv gerne total antal *hvide* stagelys: Angiv alternativt andel i procent:
Spørgsmål 5
Hvilke mærker af stagelys forhandler I? (fx ASP-Holmblad, Broste Copenhagen, Windsor, ...)
Spørgsmål 6
Hvilke forskellige vokstyper er de forskellige stagelys fremstillet af? (fx stearin, paraffin, bivoks, hærdede vegetabilske olier, andre...) Angiv andel af stagelys af stearin, paraffin, osv. ud af jeres samlede salg (evt. i procent): Ved voksblandinger, hvor det ikke er 100% rene vokstyper, angiv gerne et blandingsforhold:
Spørgsmål 7
Hvilke kriterier udvælger I jeres stagelys til salg i jeres butik ud fra? (fx vokstype, voksrenhed, brændetid, produktionsland, Svanemærket, farveudvalg, sæson/højtider, pris, andet...)

Spørgsmål 8
Sælger I Svanemærkede stagelys? Hvis ja, hvor stor andel af jeres stagelys er Svanemærket?

Spørgsmål 9
Sælger I speciallys fra fx mindre selvstændige producenter? Hvis ja, hvilke? Hvis nej, hvorfor ikke?

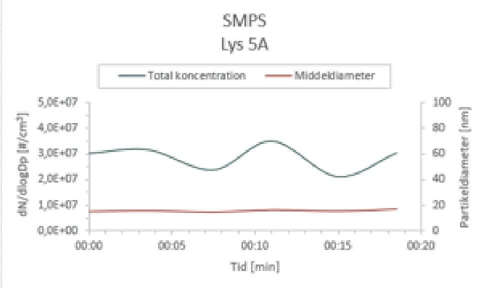
Spørgsmål 10
Er prisen afgørende for, hvilke lys I har i jeres portefølje? Hvis ja, hvad er jeres maksimumspris? Hvis ja, hvad er kundernes maksimumspris?

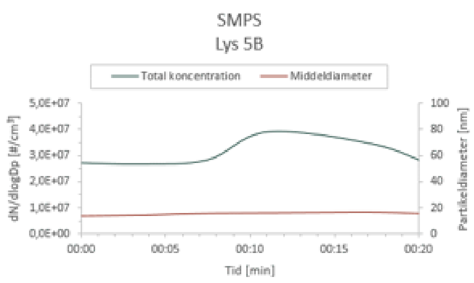
Spørgsmål 11
Vælger/fravælger I stagelys på baggrund af produktionsland? Hvis ja, hvilke produktionslande fravælger I? Er der nogle produktionslande/-områder, som I foretrækker? (fx EU, USA, Danmark, Kina, ...)

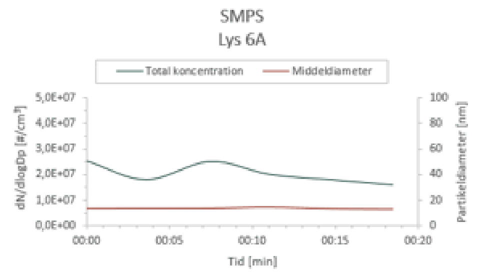
Spørgsmål 12
Har I kendskab til vægetype i de stagelys, som I forhandler? (fx speciel imprægnering af bomuldsvæge) Hvis ja, hvilke forskellige vægetyper er der i de stagelys, som I forhandler? Hvis ja, bruger I viden om vægetyper til at vælge/fravælge stagelys i jeres portefølje?

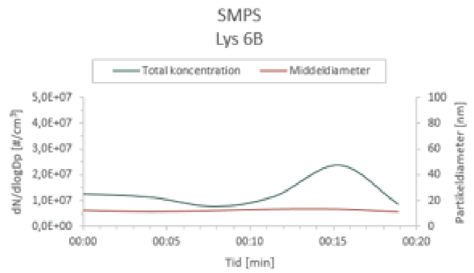
Bilag 2.

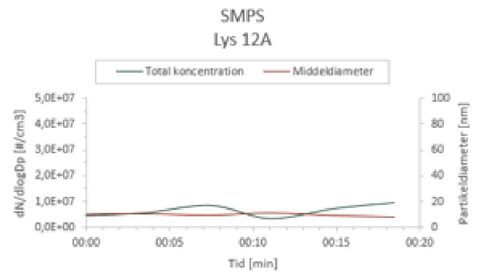
Particle number measurements

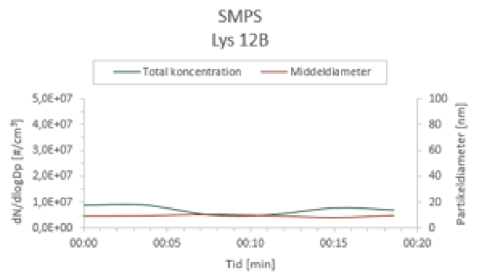


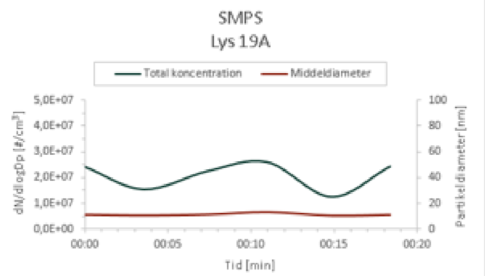


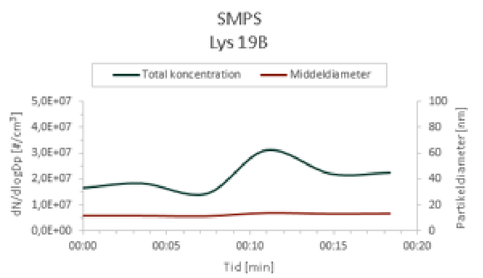


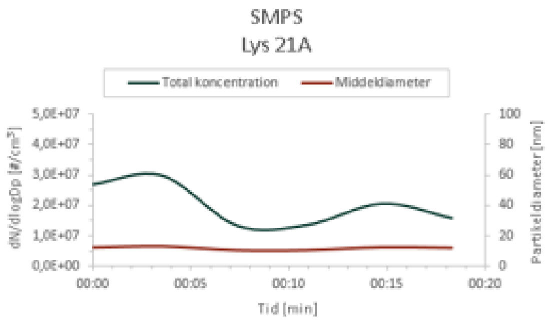


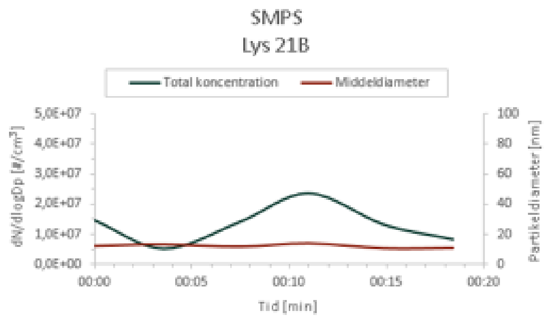









SMPS
Lys 21A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]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Lys 21B
Total koncentration
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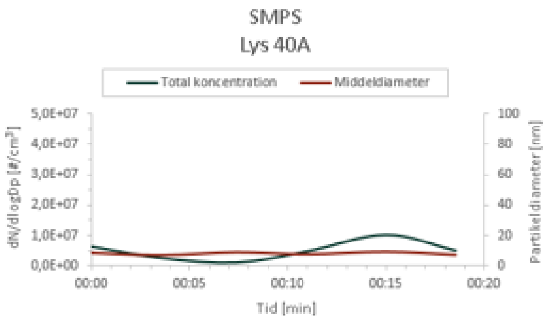
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]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Lys 40A
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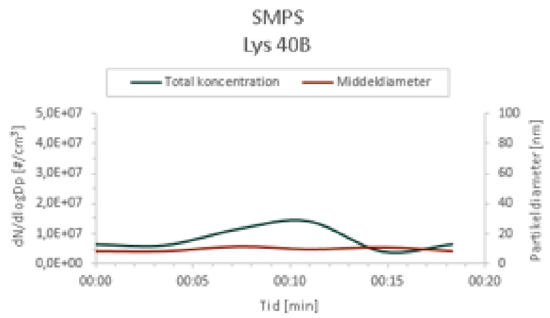
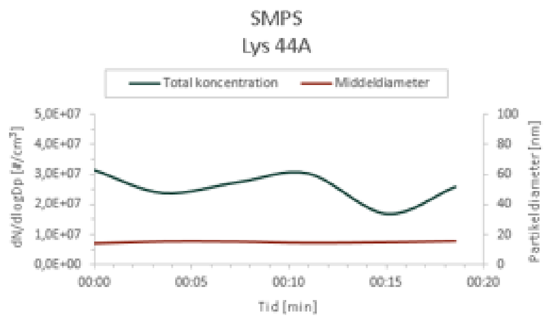
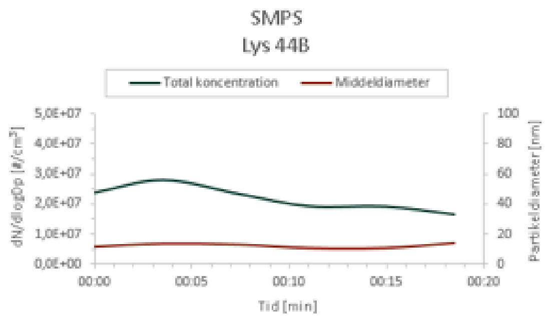
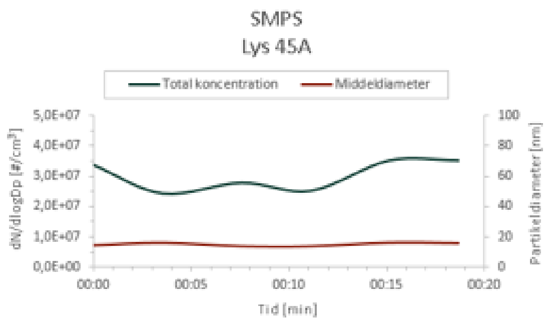
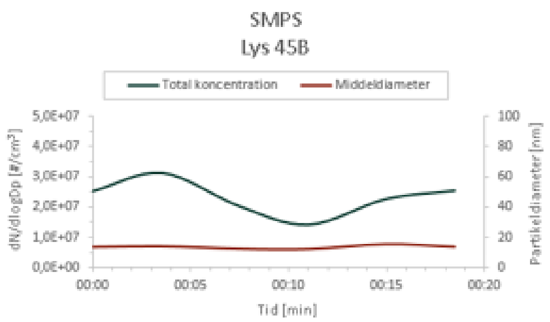
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

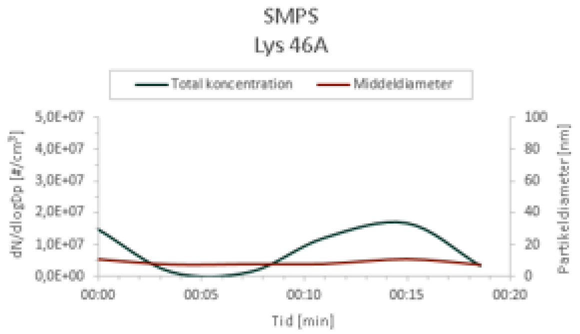

SMPS
Lys 40B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

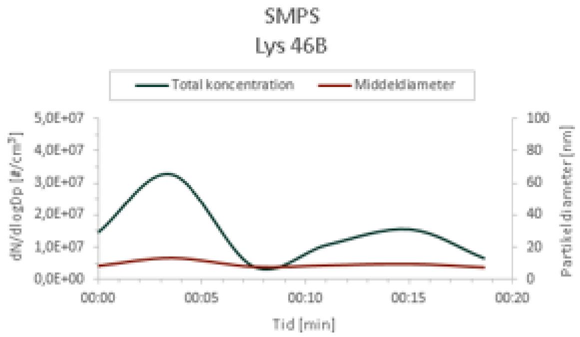

SMPS
Lys 44A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

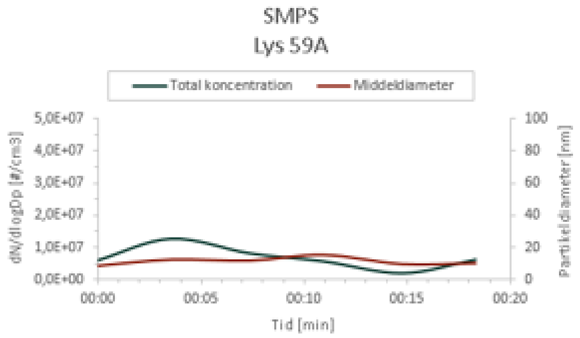

SMPS
Lys 44B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 45A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 45B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 46A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
5,0E+07
4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
Partikeldiameter [nm]
100
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20
Tid [min]


SMPS
Lys 46B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
5,0E+07
4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
Partikeldiameter [nm]
100
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20
Tid [min]


SMPS
Lys 59A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm3]
5,0E+07
4,0E+07
3,0E+07
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0,0E+00
Partikeldiameter [nm]
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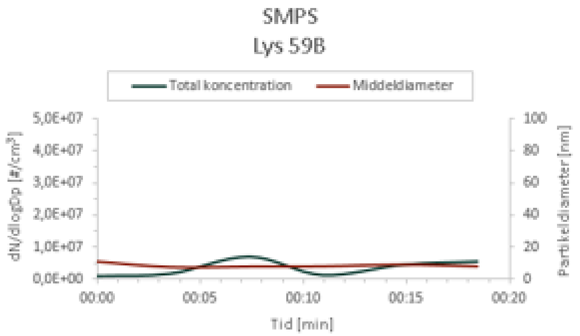
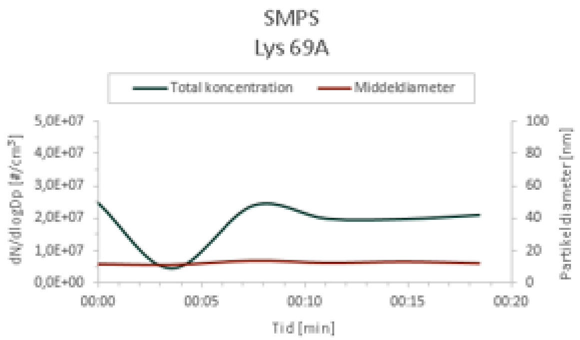
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20
Tid [min]


SMPS
Lys 59B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
5,0E+07
4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
Partikeldiameter [nm]
100
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20
Tid [min]


SMPS
Lys 69A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
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4,0E+07
3,0E+07
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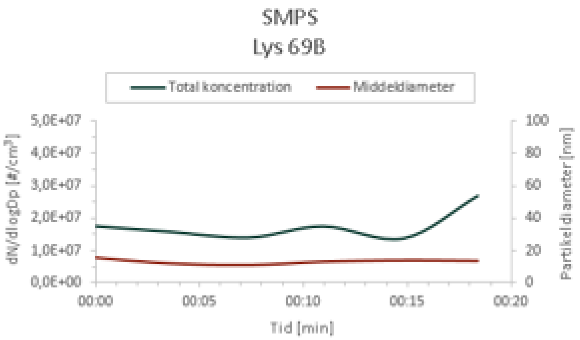
1,0E+07
0,0E+00
Partikeldiameter [nm]
100
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20
Tid [min]


SMPS
Lys 69B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
5,0E+07
4,0E+07
3,0E+07
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1,0E+07
0,0E+00
Partikeldiameter [nm]
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80
60
40
20
0
00:00
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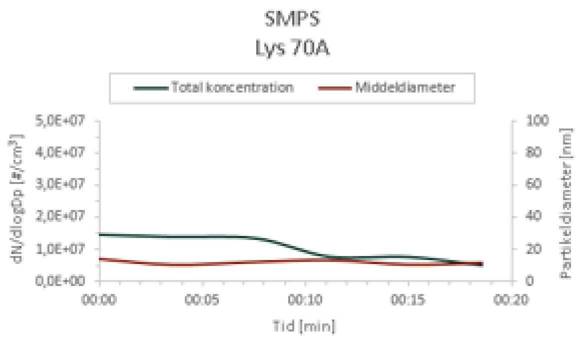
00:10
00:15
00:20
Tid [min]


SMPS
Lys 70A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
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0,0E+00
Partikeldiameter [nm]
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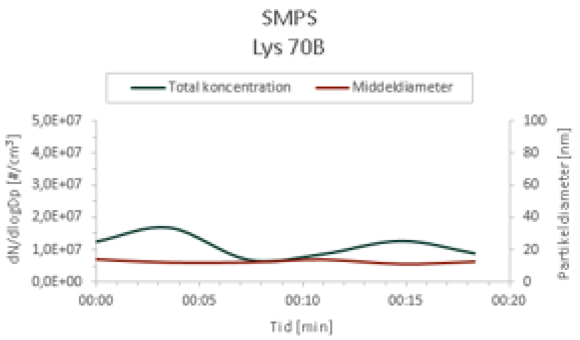
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20
Tid [min]


SMPS
Lys 70B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
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4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
Partikeldiameter [nm]
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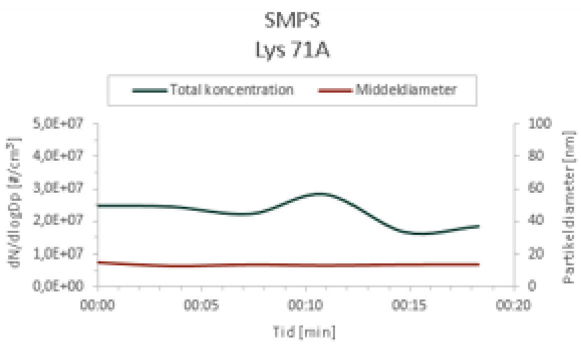
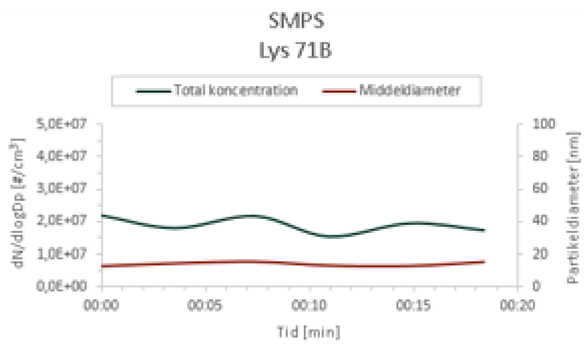
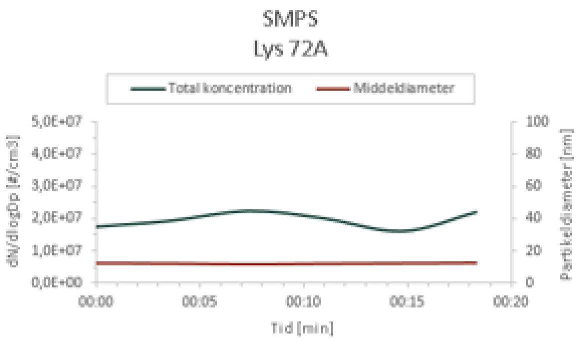
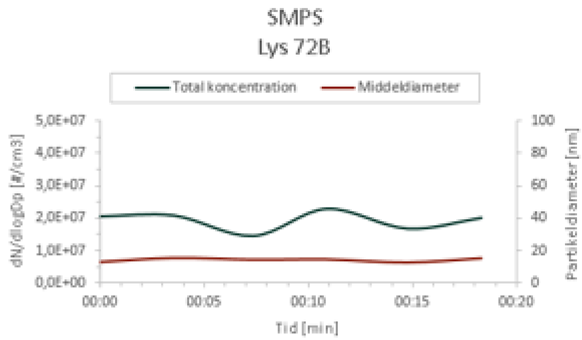
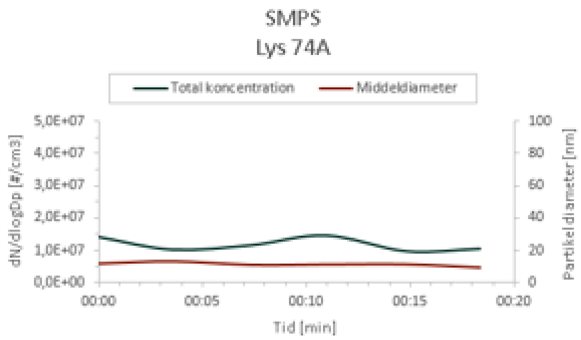
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20
Tid [min]

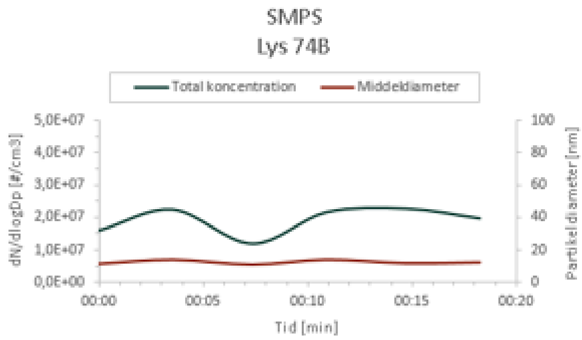

SMPS
Lys 71A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm^3]
Partikeldiameter [nm]
Tid [min]

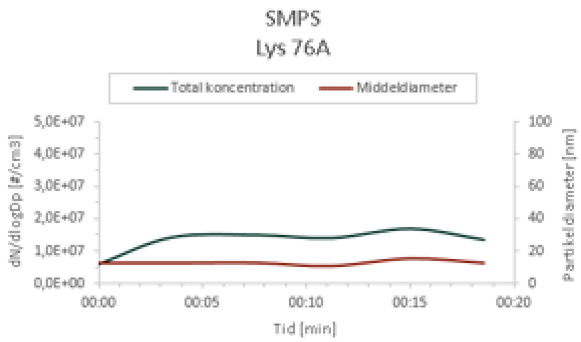

SMPS
Lys 71B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm^3]
Partikeldiameter [nm]
Tid [min]

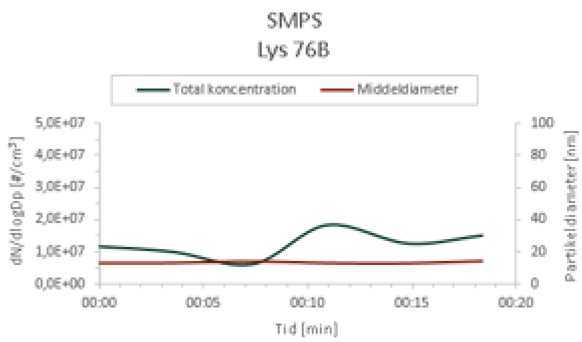

SMPS
Lys 72A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm3]
Partikeldiameter [nm]
Tid [min]

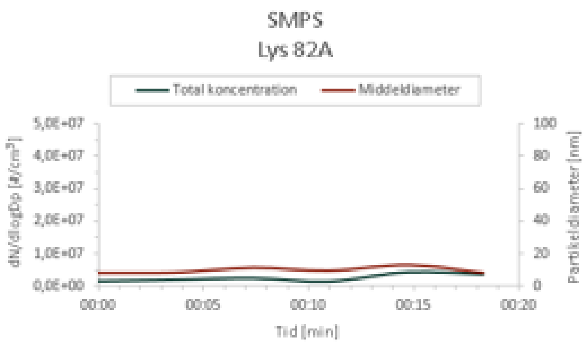

SMPS
Lys 72B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm3]
Partikeldiameter [nm]
Tid [min]

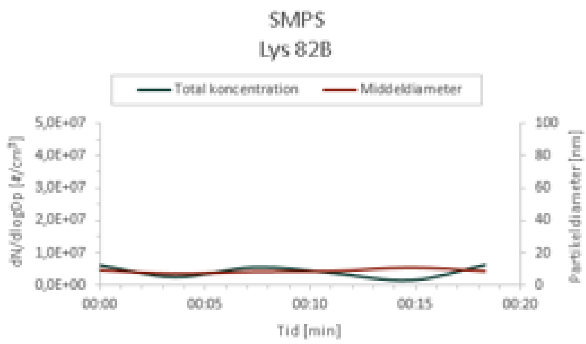

SMPS
Lys 74A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm3]
Partikeldiameter [nm]
Tid [min]

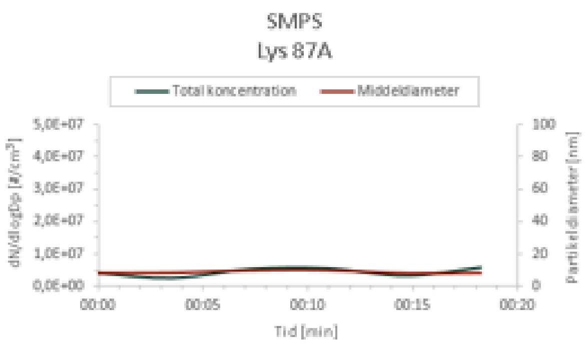

SMPS
Lys 74B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm3]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 76A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm3]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 76B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm^3]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 82A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]
5,0E+07
4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
100
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20


SMPS
Lys 82B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]
5,0E+07
4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
100
80
60
40
20
0
00:00
00:05
00:10
00:15
00:20


SMPS
Lys 87A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]
5,0E+07
4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
100
80
60
40
20
0
00:00
00:05
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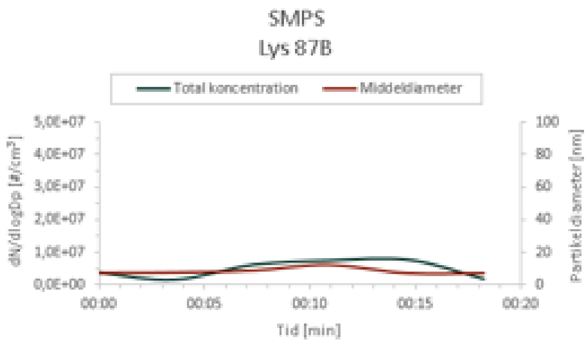
00:15
00:20


SMPS
Lys 87B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]
5,0E+07
4,0E+07
3,0E+07
2,0E+07
1,0E+07
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100
80
60
40
20
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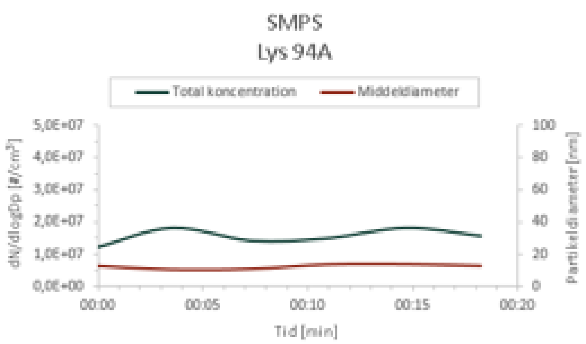
SMPS
Lys 94A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]
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4,0E+07
3,0E+07
2,0E+07
1,0E+07
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100
80
60
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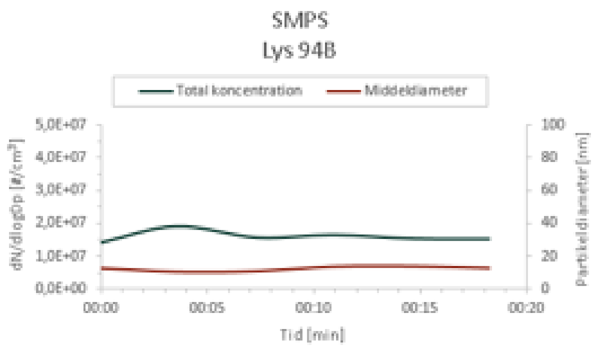
SMPS
Lys 94B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]
5,0E+07
4,0E+07
3,0E+07
2,0E+07
1,0E+07
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100
80
60
40
20
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00:00
00:05
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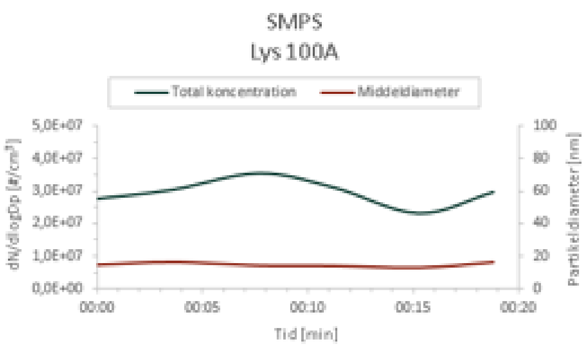
00:15
00:20


SMPS
Lys 100A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]
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4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
100
80
60
40
20
0
00:00
00:05
00:10
00:15
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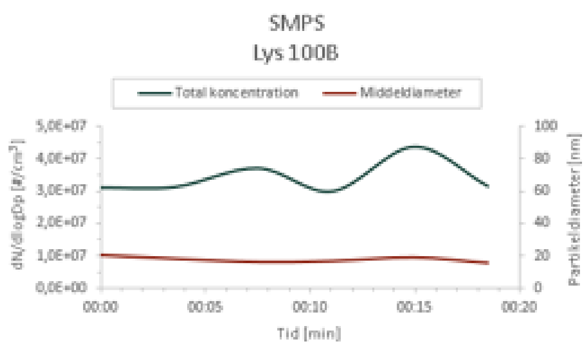
SMPS
Lys 100B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]
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4,0E+07
3,0E+07
2,0E+07
1,0E+07
0,0E+00
100
80
60
40
20
0
00:00
00:05
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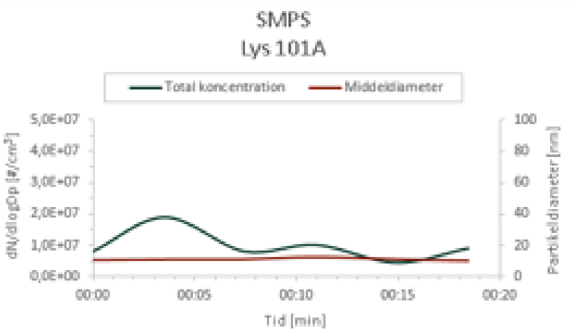
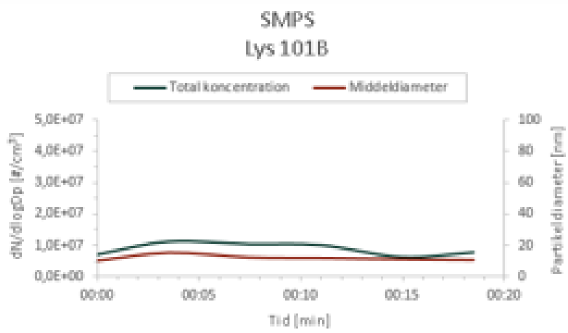
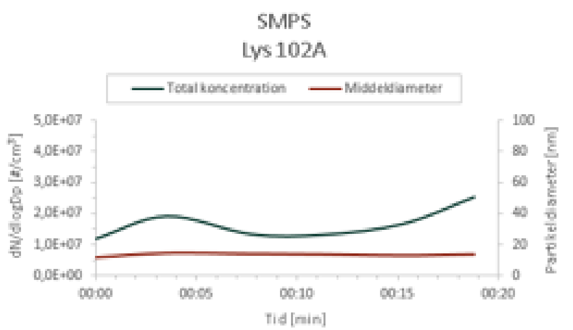
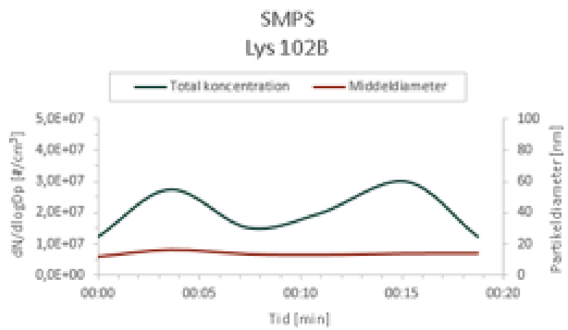
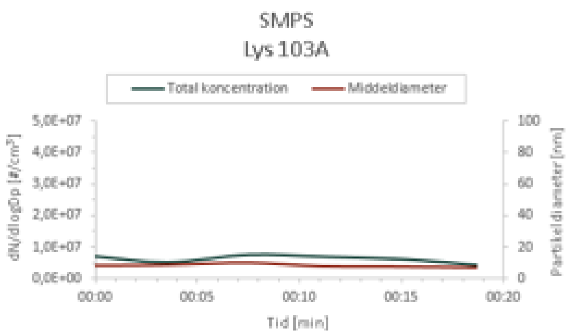
00:15
00:20

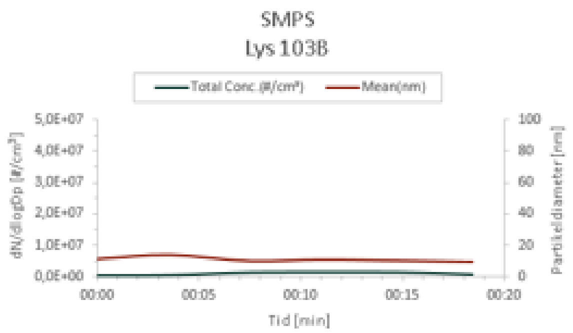

SMPS
Lys 101A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

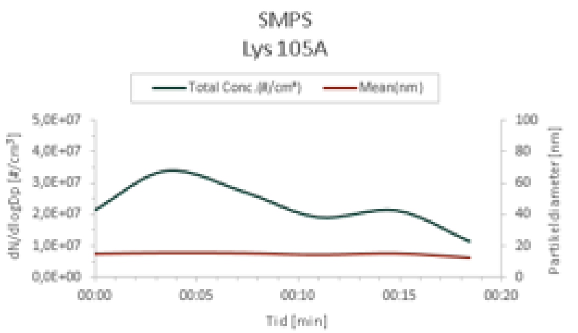

SMPS
Lys 101B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

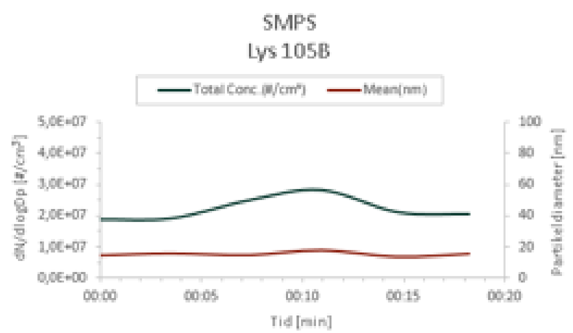

SMPS
Lys 102A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

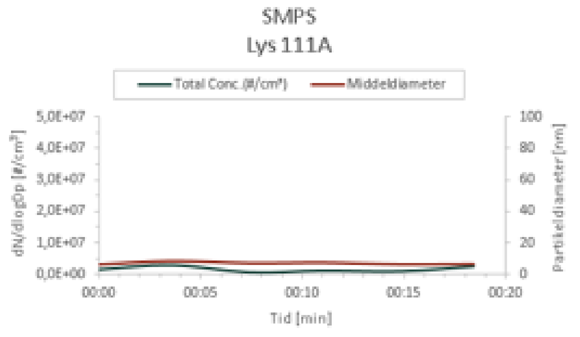

SMPS
Lys 102B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

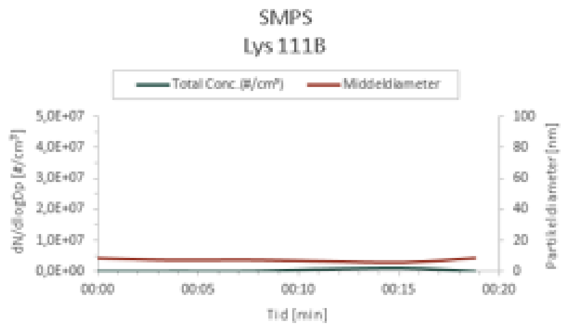

SMPS
Lys 103A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

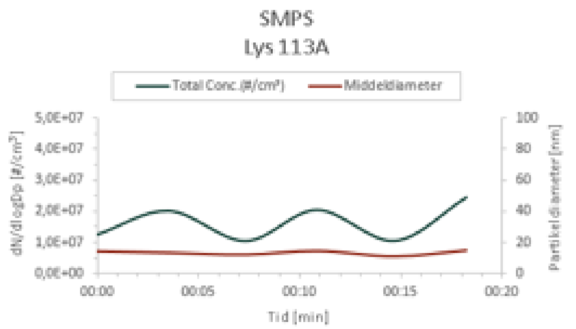

SMPS
Lys 103B
Total Conc. (#/cm³)
Mean(nm)
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

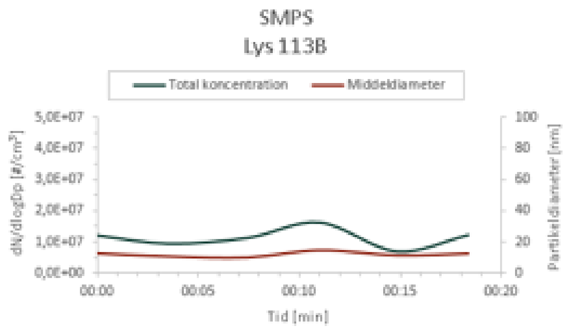

SMPS
Lys 105A
Total Conc. (#/cm³)
Mean(nm)
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

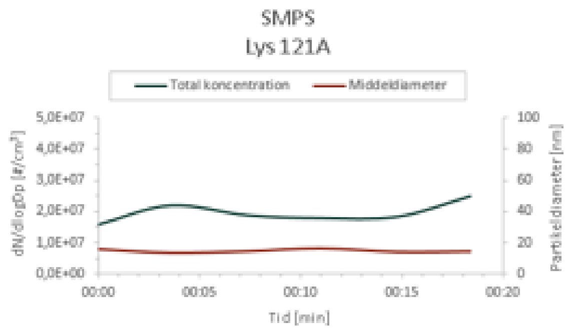

SMPS
Lys 105B
Total Conc. (#/cm³)
Mean(nm)
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

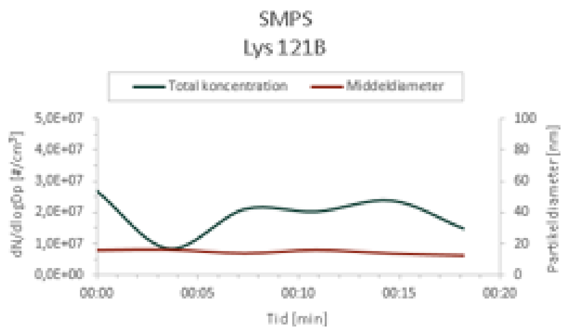

SMPS
Lys 111A
Total Conc.(#/cm³)
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

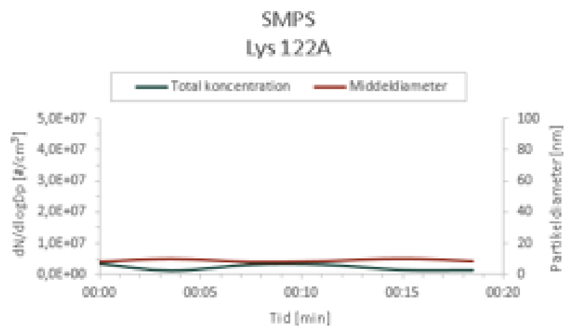

SMPS
Lys 111B
Total Conc.(#/cm³)
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

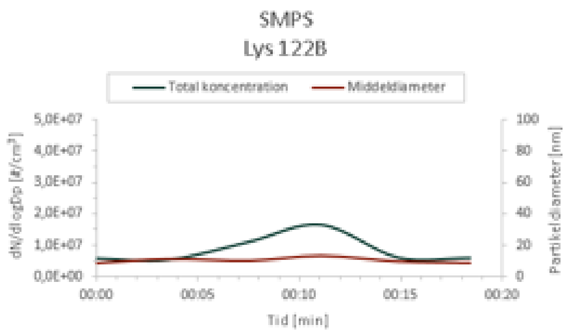

SMPS
Lys 113A
Total Conc.(#/cm³)
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

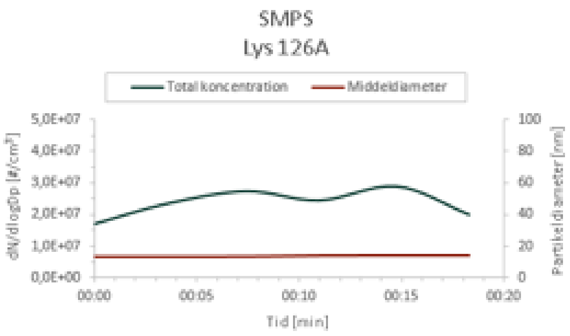

SMPS
Lys 113B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

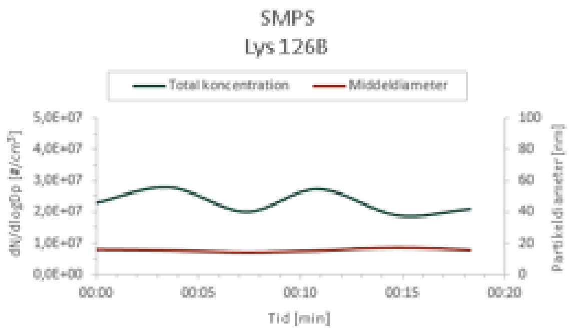

SMPS
Lys 121A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

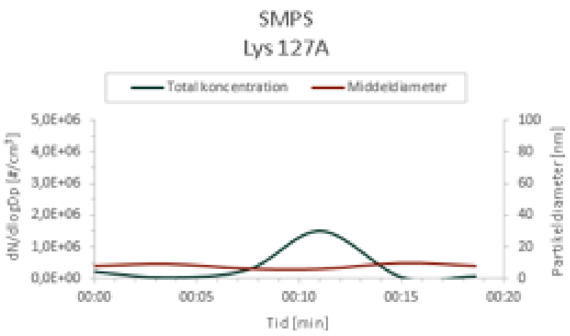

SMPS
Lys 121B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 122A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 122B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 126A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 126B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]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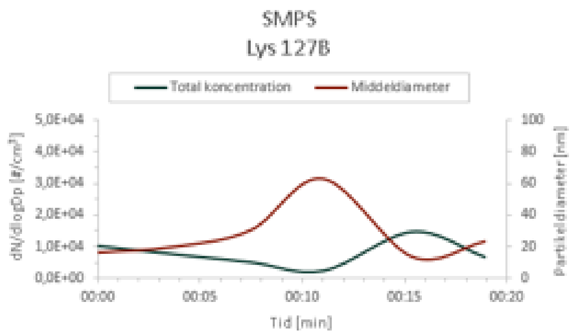
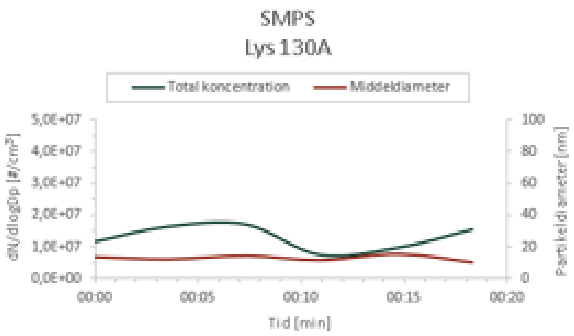
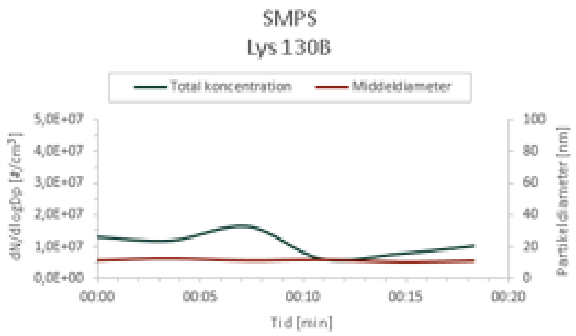
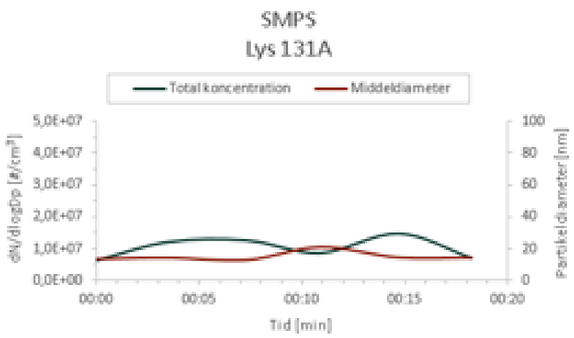
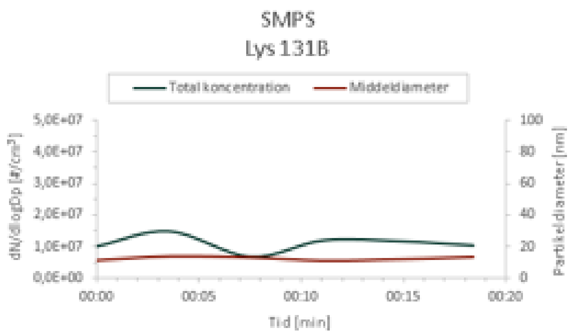
Lys 127A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]


SMPS
Lys 127B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

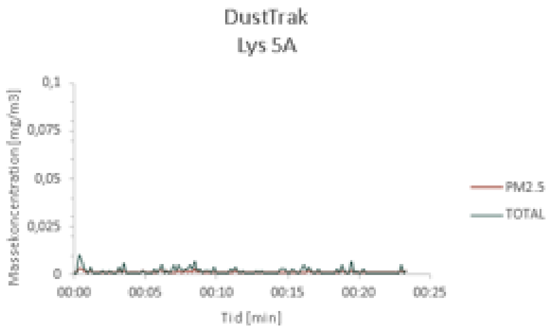

SMPS
Lys 130A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

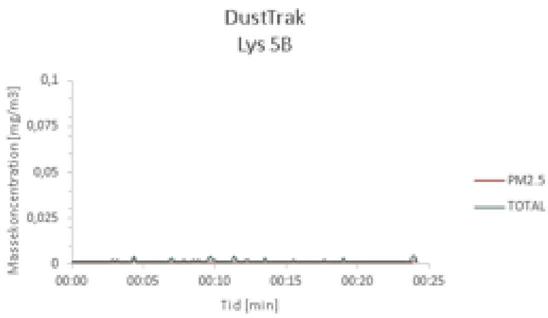

SMPS
Lys 130B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

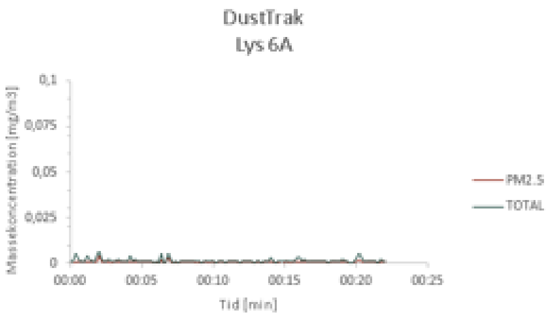

SMPS
Lys 131A
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

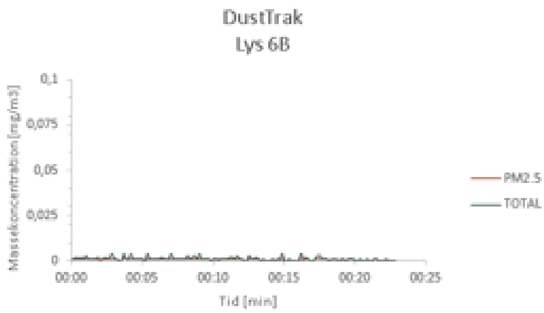

SMPS
Lys 131B
Total koncentration
Middeldiameter
dN/dlogDp [#/cm³]
Partikeldiameter [nm]
Tid [min]

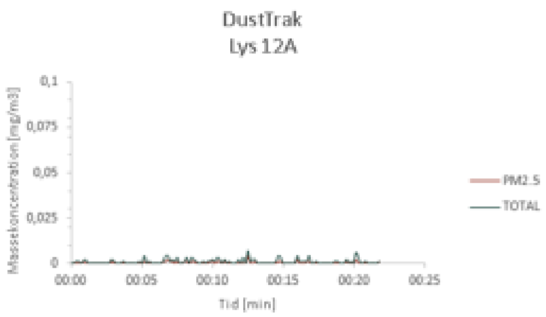
Bilag 3. Particle mass measurements

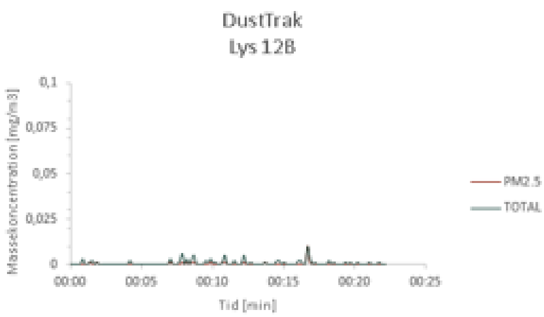


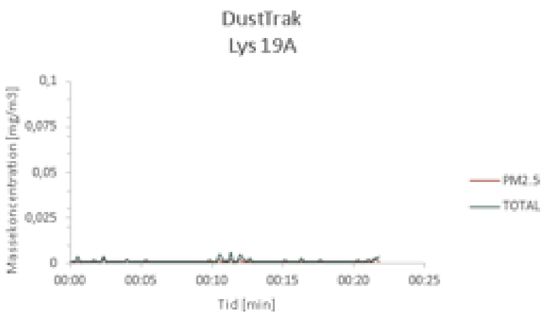


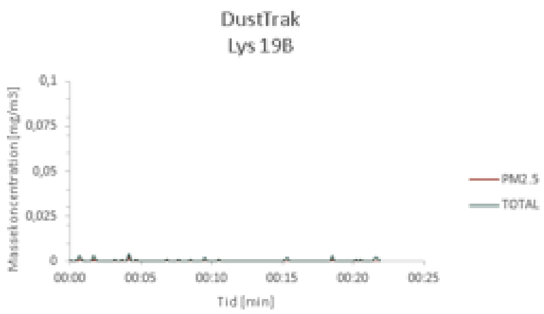


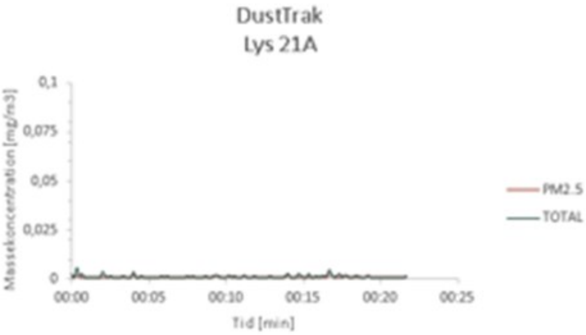


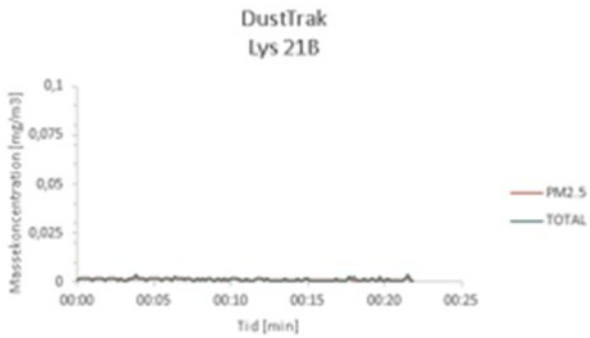


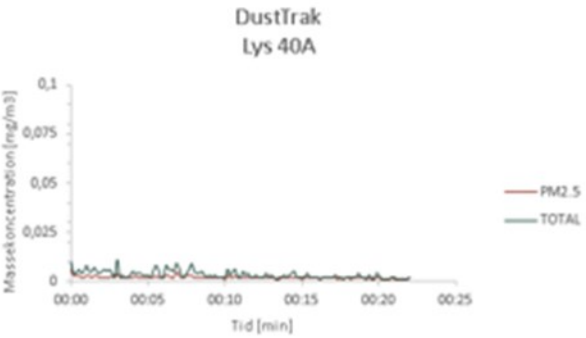







DustTrak
Lys 21A
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 21B
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 40A
Massekoncentration [mg/m3]
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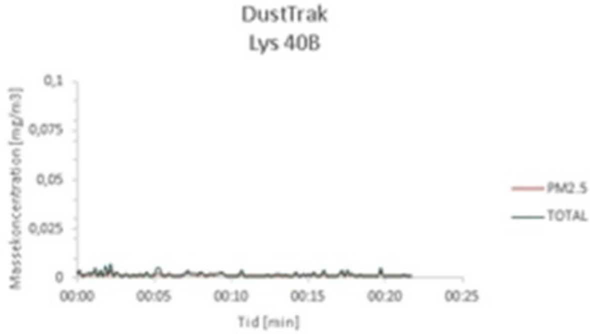
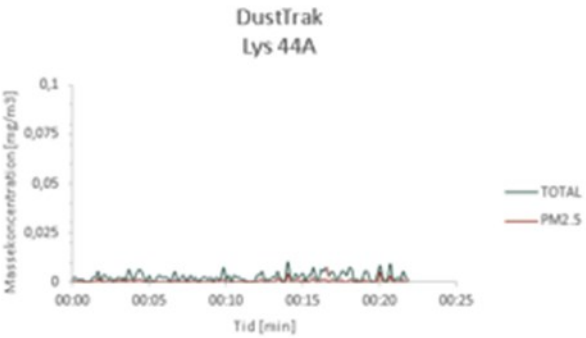
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 40B
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 44A
Massekoncentration [mg/m3]
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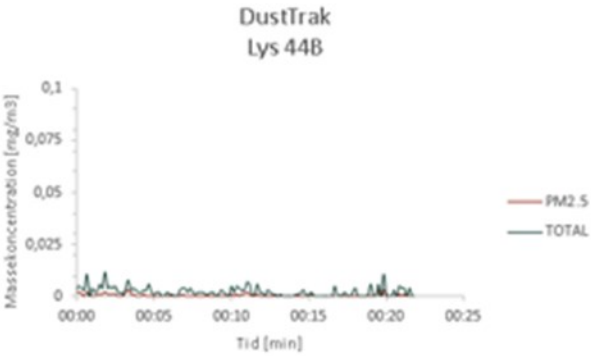
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
TOTAL
PM2.5


DustTrak
Lys 44B
Massekoncentration [mg/m3]
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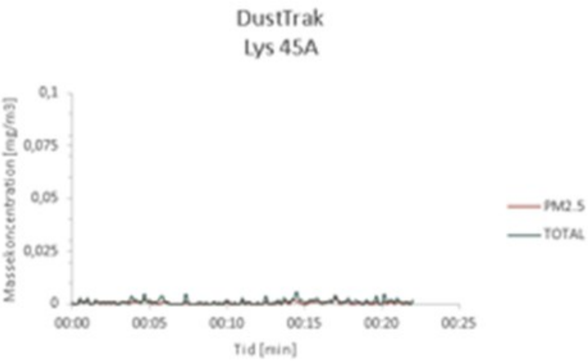
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 45A
Massekoncentration [mg/m3]
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0,025
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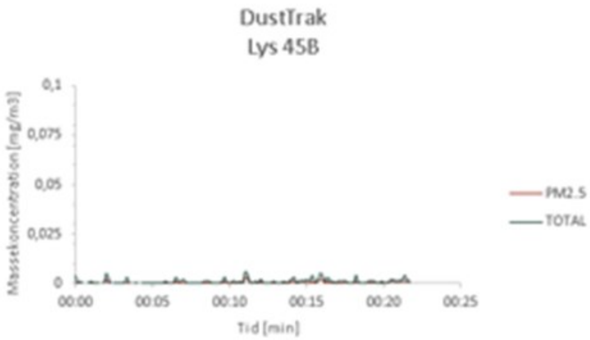
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 45B
Massekoncentration [mg/m3]
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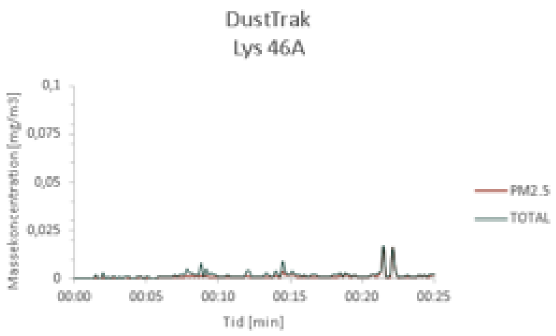
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 46A
Massekoncentration [mg/m3]
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0,075
0,05
0,025
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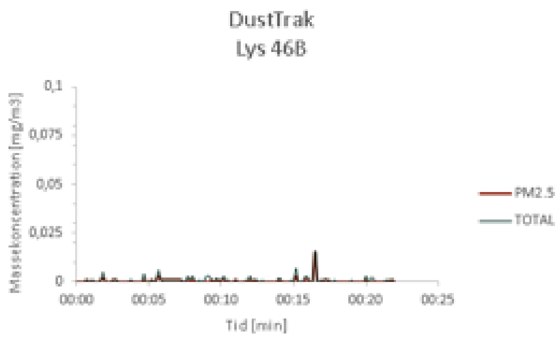
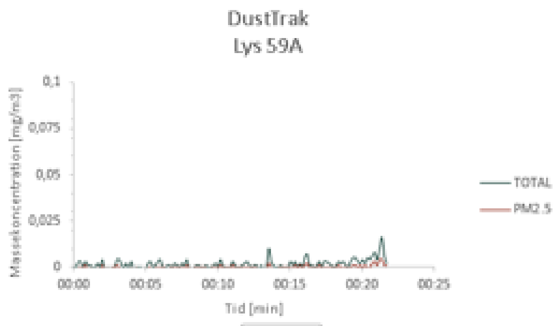
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 46B
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 59A
Massekoncentration [mg/m3]
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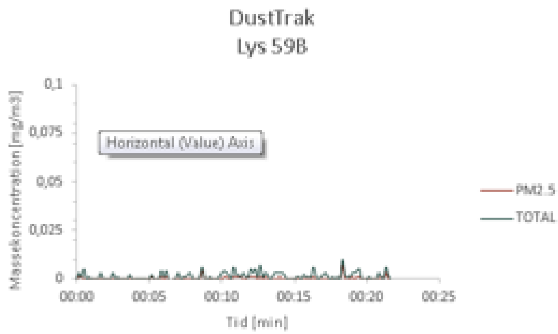
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
TOTAL
PM2.5


DustTrak
Lys 59B
Massekoncentration [mg/m3]
Horizontal (Value) Axis
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0,075
0,05
0,025
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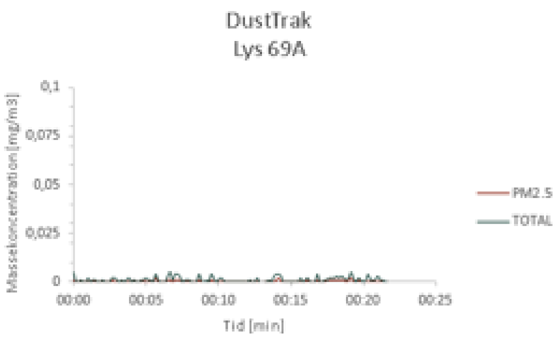
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 69A
Massekoncentration [mg/m3]
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0,025
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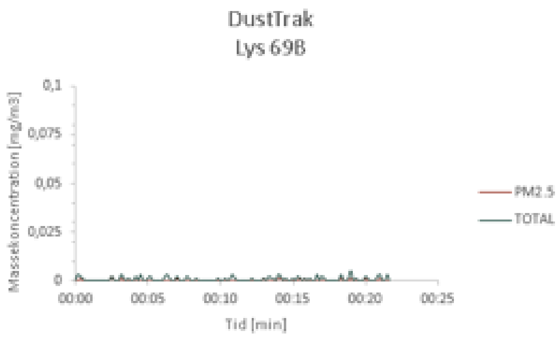
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 69B
Massekoncentration [mg/m3]
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0,025
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00:00
00:05
00:10
00:15
00:20
00:25
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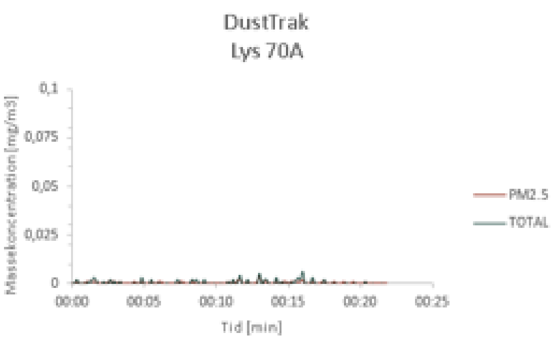
PM2.5
TOTAL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Lys 70A
Massekoncentration [mg/m3]
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00:00
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00:25
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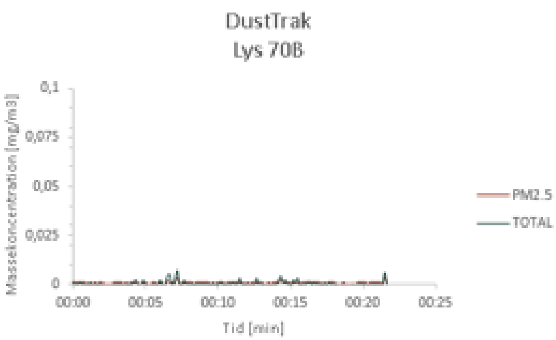
PM2.5
TOTAL


DustTrak
Lys 70B
Massekoncentration [mg/m3]
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0,075
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0,025
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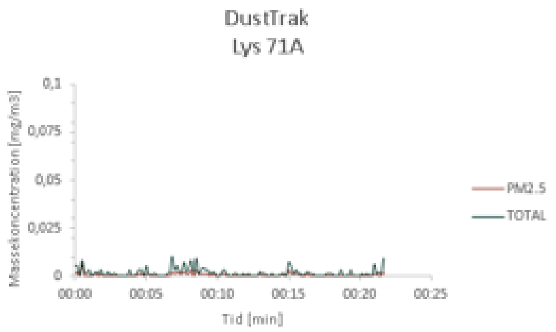
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 71A
Massekoncentration [mg/m3]
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0,075
0,05
0,025
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00:00
00:05
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00:15
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00:25
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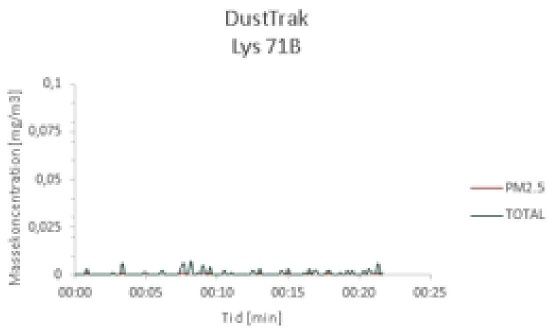
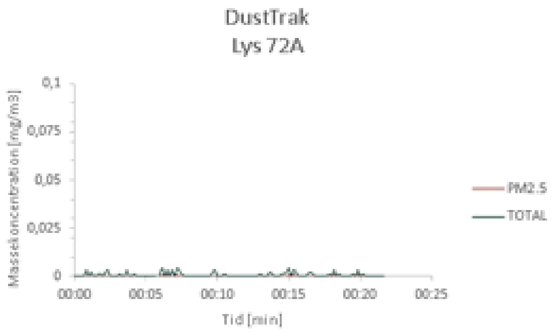
PM2.5
TOTAL


DustTrak
Lys 71B
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 72A
Massekoncentration [mg/m3]
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0,075
0,05
0,025
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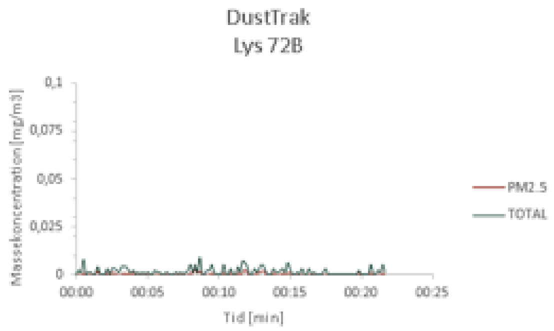
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 72B
Massekoncentration [mg/m3]
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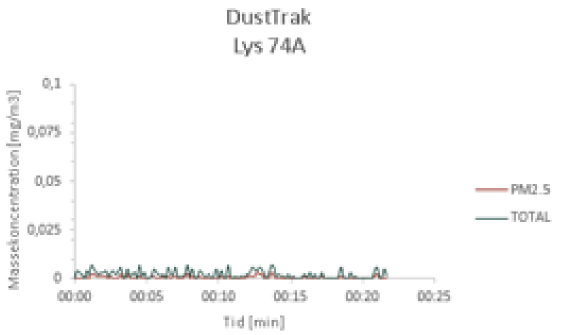
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 74A
Massekoncentration [mg/m3]
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0,05
0,025
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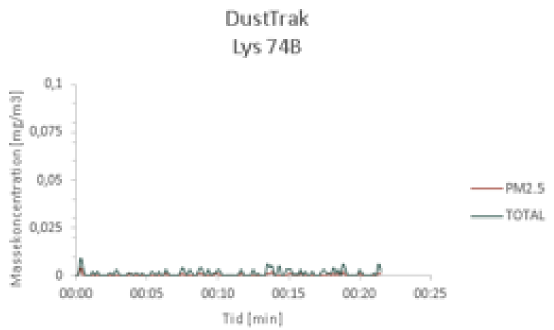
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 74B
Massekoncentration [mg/m3]
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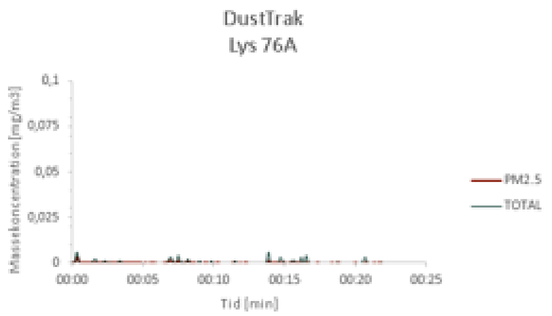
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 76A
Massekoncentration [mg/m3]
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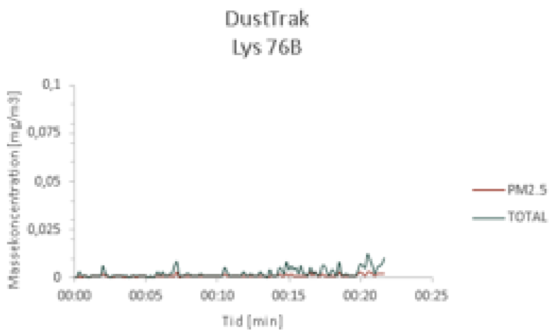
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 76B
Massekoncentration [mg/m3]
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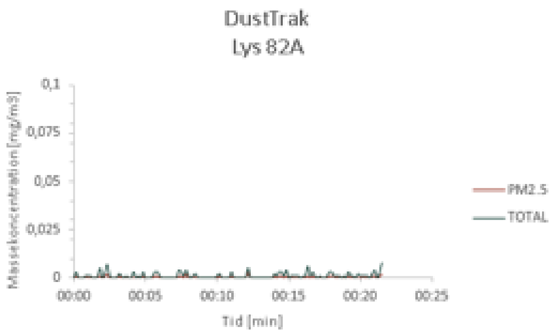
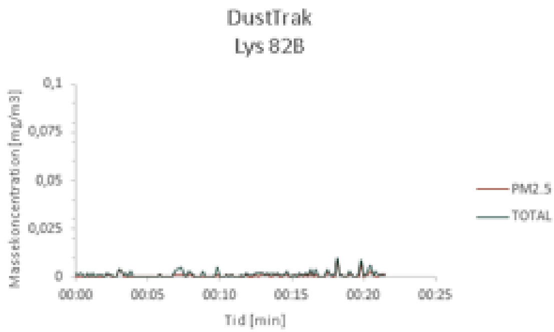
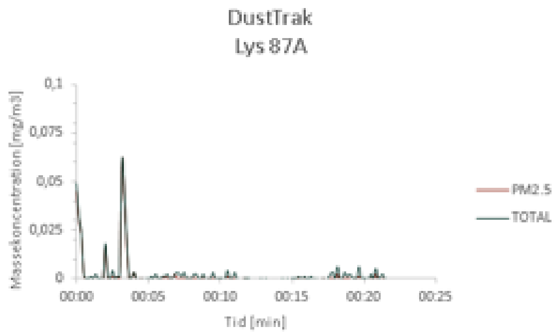
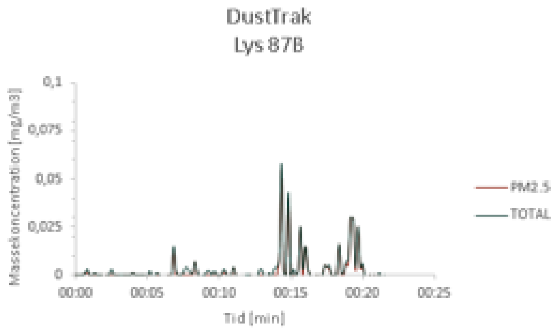
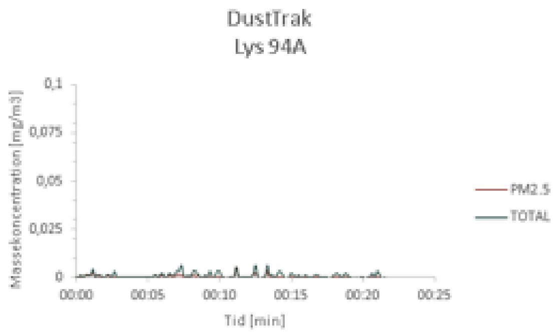
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL

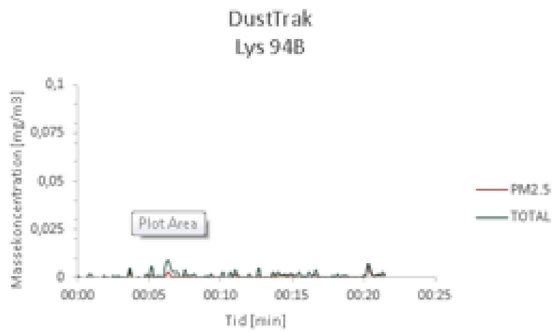

DustTrak
Lys 82A
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 82B
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 87A
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 87B
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 94A
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
00:00
00:05
00:10
00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 94B
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
0
Plot Area
00:00
00:05
00:10
00:15
00:20
00:25
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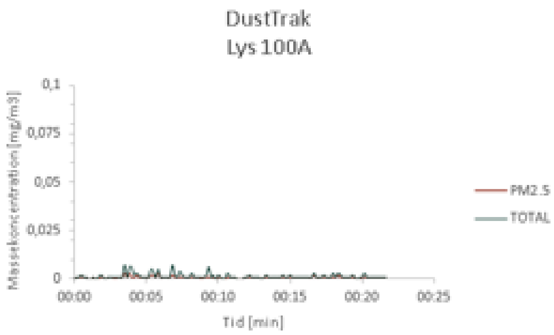
PM2.5
TOTAL


DustTrak
Lys 100A
Massekoncentration [mg/m3]
0,1
0,075
0,05
0,025
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00:00
00:05
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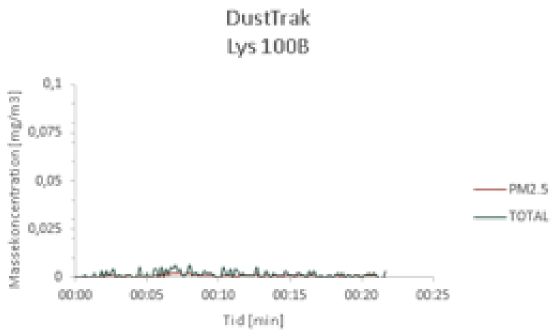
PM2.5
TOTAL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Lys 100B
Massekoncentration [mg/m3]
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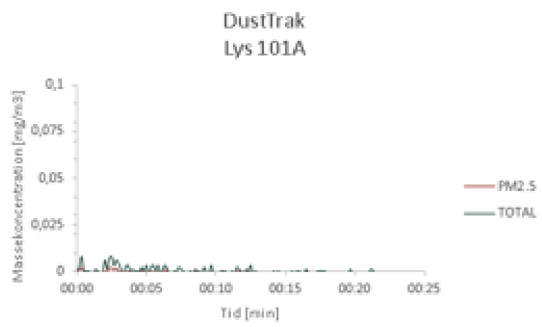
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 101A
Massekoncentration [mg/m3]
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0,025
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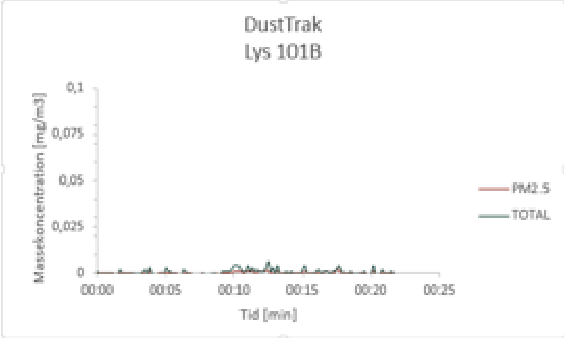
TOTAL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Lys 101B
Massekoncentration [mg/m3]
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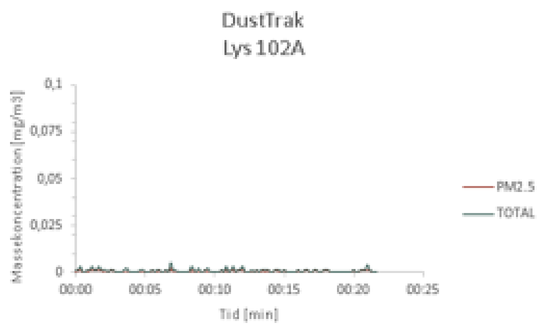
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Lys 102A
Massekoncentration [mg/m3]
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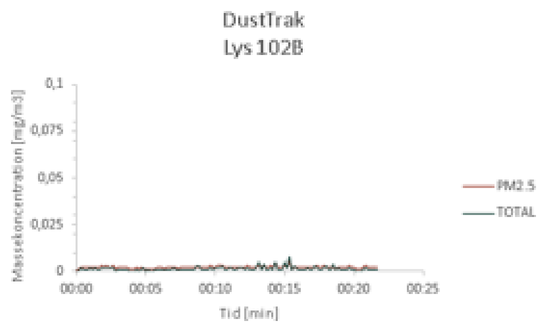
TOTAL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Lys 102B
Massekoncentration [mg/m3]
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00:25
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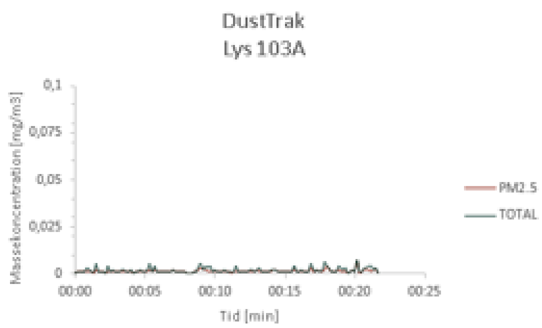
TOTAL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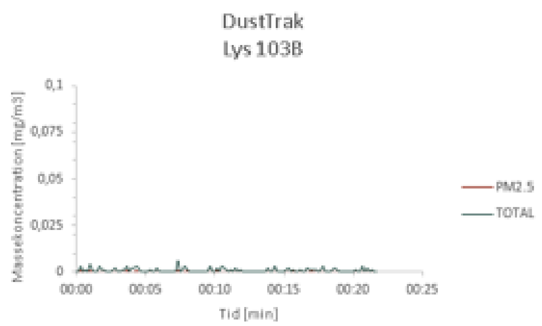
TOTAL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Lys 103B
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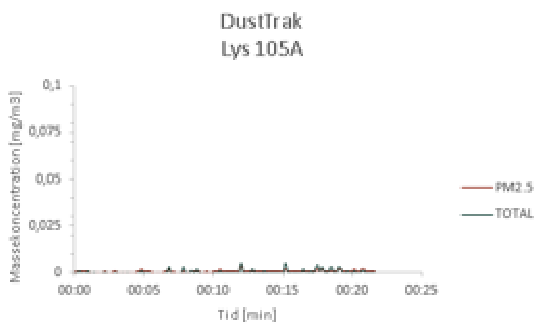
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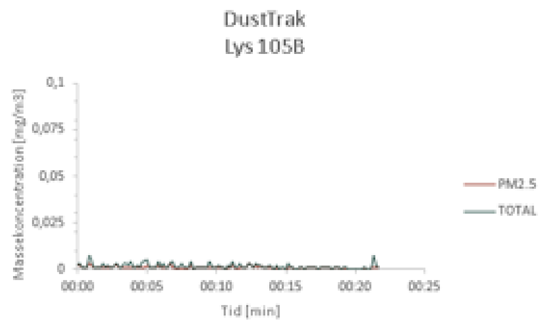
TOTAL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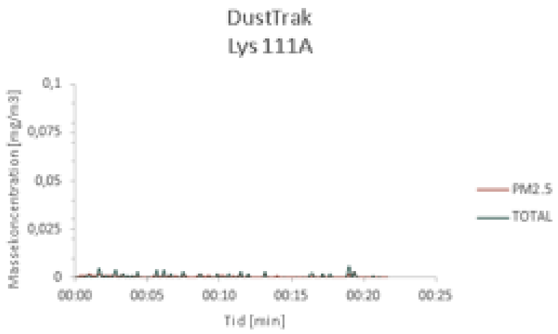
PM2.5
TOTAL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Massekoncentration [mg/m3]
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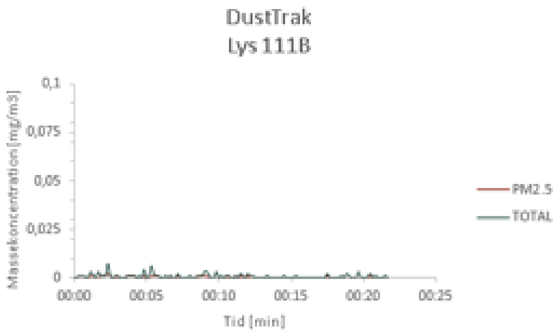
TOTAL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Lys 111B
Massekoncentration [mg/m3]
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00:15
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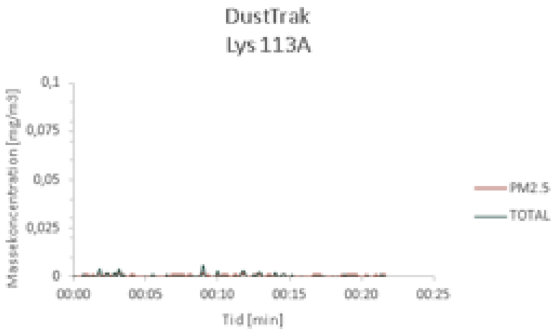
PM2.5
TOTAL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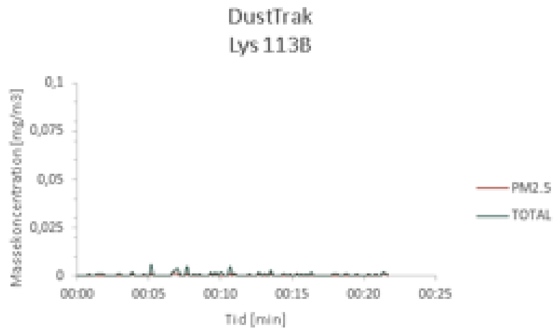
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Lys 113B
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00:15
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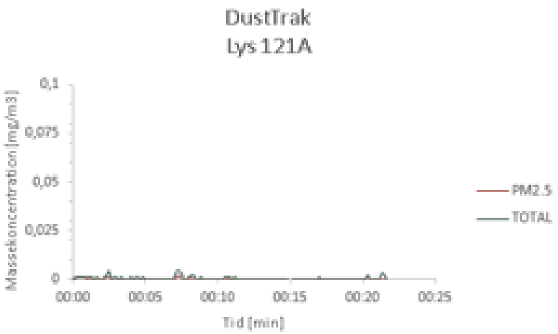
PM2.5
TOTAL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Lys 121A
Massekoncentration [mg/m3]
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0,025
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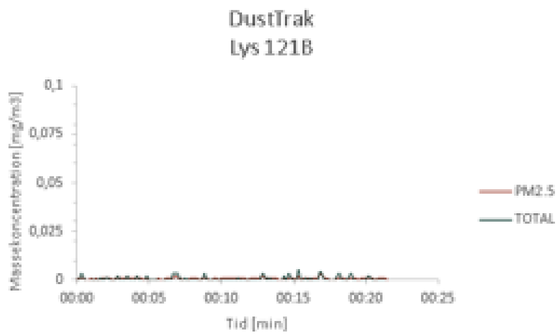
00:25
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 121B
Massekoncentration [mg/m3]
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0,025
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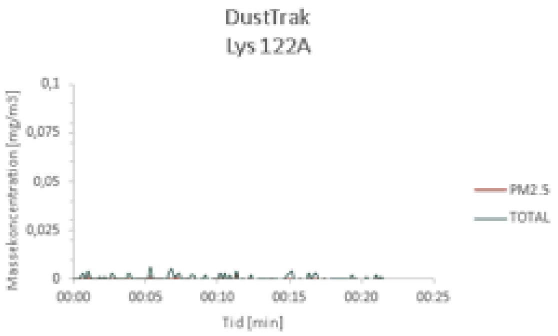
Tid [min]
PM2.5
TOTAL


DustTrak
Lys 122A
Massekoncentration [mg/m3]
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0,025
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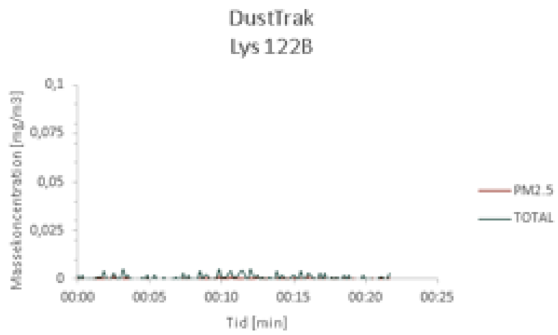
PM2.5
TOTAL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Lys 122B
Massekoncentration [mg/m3]
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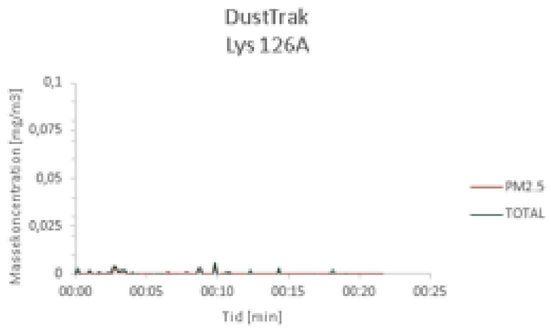
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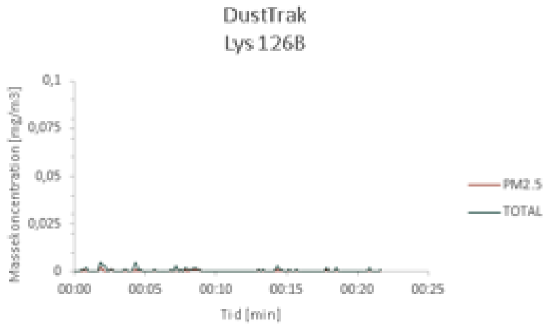
PM2.5
TOTAL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Lys 126B
Massekoncentration [mg/m3]
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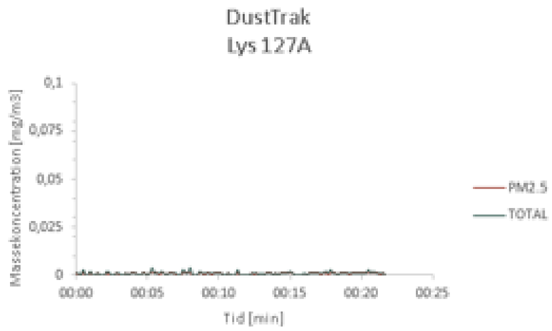
PM2.5
TOTAL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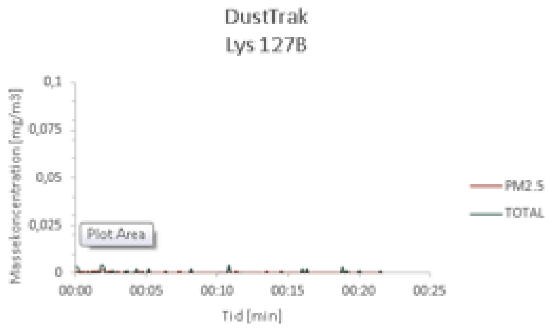
PM2.5
TOTAL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Massekoncentration [mg/m3]
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00:25
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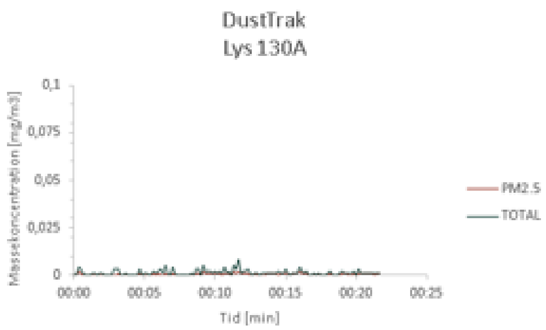
PM2.5
TOTAL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Lys 130A
Massekoncentration [mg/m3]
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0,025
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00:00
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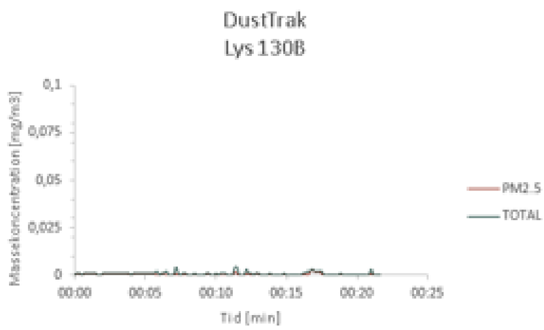
00:25
Tid [min]
PM2.5
TOTAL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Lys 130B
Massekoncentration [mg/m3]
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0,025
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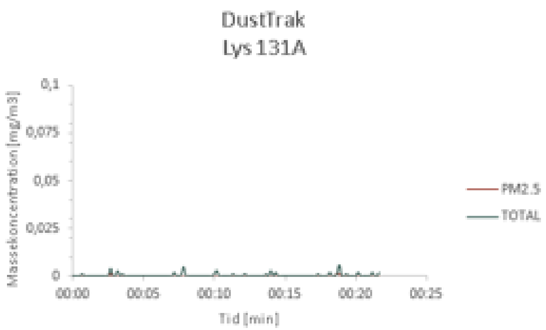
PM2.5
TOTAL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Lys 131A
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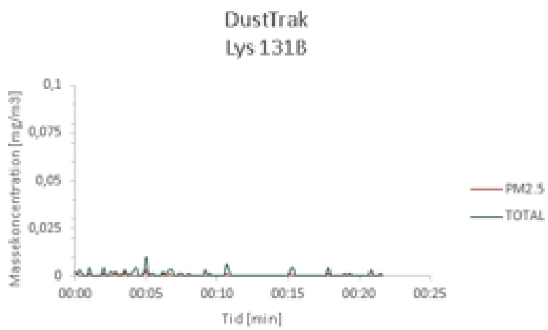
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Lys 131B
Massekoncentration [mg/m3]
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00:00
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00:15
00:20
00:25
Tid [min]
PM2.5
TOTAL

Survey and Risk Assessment of Particle and Heavy Metal Emissions from Candles

Many Danes lit candles in their homes daily or almost daily, which leads to a higher concentration of particles in the indoor air. The purpose of this report was to gather more knowledge about the particle emission from candles, and to assess whether there is a health risk associated with the indoor use of candles. The study was divided into different phases: a survey and review of exiting knowledge, analyses of candles and a health assessment. The survey identified 129 different candles for candlesticks from 56 different brands, including 32 different white candles, which were selected for subsequent analyzes. Particle emission concentration was measured both near the light source (20 cm above the flame) and in a climate room of 20 m3 (1.5 m from the lighted candles). The content of lead and nickel were also analyzed in the wax and the wick and in particles collected on filters. The study found that lit candles, that burn with an optimal combustion, emit a large number of particles but a relatively small particle mass. However, the estimated exposure levels based on these results were not associated with health risks. The measured levels of lead and nickel in the candles were below the EU limit values and the obtained exposure levels did not lead to health concerns. Assessment based on measurements from another study found in the literature showed higher and more concerned exposure levels to particle emissions. The study from the literature also measured particle emissions under sooting combustion,. Based on this the advice is to choose candles that burn with a stable and non-sooting flame, as this will reduce particle emission significantly.

Environmental
Protection Agency
Strandgade 29
DK-1401 København K

www.mst.dk