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Street dust emissions in Finnish cities – summary of results from 2006–2010

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1 Introduction

Vehicles affect the amount of particles in the ambient air through exhaust gas emissions, but particles are also formed in mechanical processes. Non-exhaust particles include abrasion products from the interaction processes between road surface and tyre, brakes and engine. In addition particles that are deposited on or in the vicinity of roads may be re-suspended back into the air through vehicle-induced turbulence. A commonly used term for these particles is “road dust”.

Road dust constitutes a remarkable share of respirable dust (PM_{10}) concentrations especially during spring time in the sub-arctic regions of the world such as Scandinavia, North America and Japan. It is proposed that the high concentrations of road dust result from the traction control methods used in these areas due to snowy winter conditions. Traction control methods include the use of traction sand and melting of ice with saline solutions. In addition, special winter tyres are used in cars, either studded winter tyres or specially designed friction tyres. Several of these methods enhance the formation of mineral particles from the pavement wear or traction sand. These particles accumulate in the road environment during winter. In the springtime when the snow and ice melt and surfaces dry out, a lot of these particles end up airborne especially due to traffic-induced turbulence.

Springtime road dust is still one of the most challenging problems in the field of air pollution control in Finland, even though a lot of work in order to combat the problem has been done in several municipalities. The EU limit value for daily concentrations of PM_{10} was exceeded in Helsinki in Runeberginkatu (2003), Hämeentie (2005), Mannerheimintie (2005, 2006) and Töölöntulli (2006). Also in other cities concentrations are occasionally high enough to have adverse effects. Due to the exceedances the city of Helsinki has been obliged to draft an air protection program and report the exceedances to the Ministry of the Environment and the EU commission.

Studies show that springtime road dust is largely composed of mineral particles originating from the abrasion of traction sand and pavement wear. Recent studies indicate that both sources increase the formation of road dust (Kupiainen et al. 2003, Kuhns et al. 2003, Gustafsson et al. 2005, Tervahattu et al. 2006, Kupiainen et al. 2007, Kupiainen 2007) and therefore affect the particle concentrations in the ambient air.

Based on current knowledge it is likely that the significance of different sources varies in different environments depending for example on traction sanding practices (the amount of sand used, frequency of traction sanding) and the quality of traction sand (e.g. sieved, unsieved). Part of the dust might never end up in the ambient air. To be able to find out the shares of different sources of dust, more accurate source estimation for different types of city environments is needed.

In addition to high emission rates, springtime prevailing weather conditions in Finland; low wind speed, atmospheric stability and low mixing height (e.g. ground-based temperature inversion) can have adverse effects on the air quality.

1.1 KAPU project: history and definitions

This report presents the results from the KAPU-project (2006–2010). The project was aimed to study the impacts of winter maintenance and springtime street cleaning activities on the amount and composition of road dust in Finnish cities. In addition to the prevailing practices, some newly developed methods were studied. A general goal was to find out measures to lower the high spring time PM_{10} concentrations in the ambient air of Finnish cities. KAPU project was financed by the Ministry of the Environment, YTV (Helsinki Metropolitan Area Council, since 2010 known as HSY, Helsinki Region Environmental Services Authority), Association of Finnish Local and Regional Authorities (2008–2009), Destia (2006–2007) and Berner Oy (2008–2009) as well as eight Finnish cities: Helsinki, Espoo, Kerava (2006–2009), Porvoo (2010), Riihimäki, Tampere, Turku (2008–2009) and Vantaa.

All participating cities represent different types of challenges regarding winter maintenance practices. A measuring route for the Sniffer mobile laboratory was designed in all cities, and road dust concentrations were measured during different meteorological conditions in different seasons.

The measurements concentrated mainly on the spring time road dust period, when winter maintenance measures also took place, but also other seasons were covered for comparison. All operations along the routes were carefully documented. Also data about different variables such as weather conditions, air quality, traffic characteristics and pavement types were collected.

KAPU project finished at the end of 2010, but the work will continue in the REDUST project, an EU Life+ funded project benefiting from the KAPU project's results and experiences. The REDUST project is a four year demonstration project planned to last until the end of 2014.

2 Methodology

Measurements were conducted with the Sniffer vehicle (http://nuuskija.metropolia.fi), which is a mobile laboratory equipped with versatile air quality and meteorology measuring devices.

Measurements with the Sniffer vehicle were conducted on the KAPU routes

- Before the wintertime accumulation of dust begun
- During the dust accumulation period in winter
- In the spring before any street cleaning activities
- During different stages of springtime street cleaning
- After the springtime cleaning period, until the amount of dust emissions stopped going down

For the cleaning equipment tests, the measuring system was modified to fit the research purposes. The implementation of the equipment tests is described in Chapter 3.

The Sniffer vehicle (VW LT 35) collects dust sample behind the left rear tyre, approximately 5 cm from the tyre through a conical inlet with a surface area of 0.20 m x 0.22 m into a vertical tube with a diameter of 0.1 m. The lower edge of the conical inlet is 7 cm above the street surface, and the upper edge is as high as the geometry of the fender of the wheel allows. The width of the inlet is approximately 2 cm less than the width of the tire, see details in Pirjola et al. 2009.

A sampling air branch-off was constructed into the particle mass monitors TEOM (Tapered Element Oscillating Microbalance; series 1400A, Rupprecht & Patashnick) and ELPI (Electrical Low-pressure Impactor; Dekati Ltd.). In front of the van the other ELPI measured the background concentrations. However, in KAPU, PM_{10} mass concentrations have been used to interpret street dust results. Since measuring is done very close to the street surface and source, the sample has no time to dilute, and therefore, in this report the term ‘emission’ or ‘Sniffer emission’ refers to the measured mass concentrations. (Pirjola et al. 2004, Pirjola et al. 2010)

3 Results

3.1 Winter maintenance, traction control and dust binding measures

Traction control methods of the participating cities differ somewhat from each other. For example in Riihimäki, only traction sanding is used. In the other cities, sanding is replaced with using saline solutions where appropriate. There are also differences between the materials used for traction sanding. Some cities use washed and sieved crushed stone, whereas some use unsieved sand. Studies indicate that by washing/sieving the traction material it is possible to reduce the street dust problem.

3.1.1 Winter conditions and traction control measures in 2006–2010

Information about the traction control and dust binding measures carried out during the KAPU project in different cities is collected in Table 1. During the winter seasons 2005/2006 and 2006/2007 more extensive documentation was conducted only in Helsinki. During winter seasons 2005/2006 and 2007/2008 documentation was done only from the beginning of January onwards. Changes in the amount of traction control measures between different years are partly due to prevailing weather conditions.

In **2006** January was somewhat milder than average, February and March on the other hand were colder (Myllynen et al. 2007). Early spring was cold and rainy, and the actual street dust period only started in late April. For example in Helsinki traction control was mainly conducted by sanding (Table 2) and street cleaning started later than average.

Winter season **2006/2007** was warmer than average except in February. Springtime precipitation levels were normal. In March average temperatures were 3 degrees higher than average in the entire country. In the Helsinki KAPU route, traction control was mainly conducted by adding saline solution. Street cleaning actions started on the last week of March, and were finished by the end of April, 2–3 weeks earlier than previous spring.

Table 1. Traction control and dust binding registrations in all cities during the KAPU project.

		2006	2007	2008	2009	2010
Espoo	sanding	9		4–5	10–13	5–10
	salting	10		18–19	12–15	28–60
	dust binding	2–3		5–7	4–6	1–2
Helsinki *	sanding	14–40 (6–7)	13–29 (8–9)	2 (0)	0–2 (18)	55–56***
	salting	6–21 (4–6)	19–26 (19–22)	14–33 (30–31)	23–26** (39)	31***
	dust binding	2–5 (1)	0–11 (0–1)	1–9 (0–1)	0–24 (2-3)	2–8
Kerava	sanding	Partner city from 2007.	29	7	3	Partner city only until 2009.
	salting		25	23	4	
	dust binding		0	0	0	
Porvoo ****)	sanding	Partner city from 2010.				10
	salting					2–3
	dust binding					-
Riihimäki	sanding	Partner city from 2008.		Traction control is implemented by sanding. Salt is used neither in traction control nor dust binding.		Before 2010 measurements, street cleaning has been implemented with mechanical broom sweepers and washing suction nozzles
	salting					
	dust binding					
Tampere (2009 information from part of the route)	sanding	No registrations from 2006/2007.		3–18	1–8	No registrations in 2010.
	salting			1–23	8–15	
	dust binding			3	0	
Vantaa	sanding	Partner city from 2008.		1	6–7	25–28
	salting			38–39	33	23–25
	dust binding			1	2–3	2

*) Helsinki: 2008 ja 2009 information in brackets from Kallio.
**) Helsinki: In early winter 2008 traction control was mainly implemented by salting.
***) Helsinki: 2010 registrations from part of the route only.
****) Registrations from Porvoo 2010 are from the beginning of March onwards.

Winter **2007/2008** was the mildest winter ever documented in Finland. Precipitation occurred mainly as rain (Niemi et al. 2008). There was little or no need for traction sanding in the Helsinki metropolitan area KAPU routes. In year 2008 sand removal and street washing operations were conducted in KAPU routes between mid-March and late April, which is earlier than in the previous spring. Street sweeping and washing operations in Espoo and Vantaa took place between 1–17 April. In Kerava, sand removal in the KAPU route took place already between mid-March and early April, but street washing operations were still ongoing at the beginning of May.

Winter season **2007/2008** in Tampere was different from that in the metropolitan area, which is shown for example in the amount of traction sanding registrations. Temperatures close to zero, mild rain- and snowfall together with nighttime frosts made the implementation of traction control challenging. These differences point out how the conditions between different cities (for example inland–coastal areas, see Annex 1) during same year can highly affect the need of winter maintenance. Sand removal and street washing operations in the Tampere KAPU route started at the beginning of April, and were accomplished by the end of April or mid-May.

Winter season **2008/2009** in Southern Finland was milder and less rainy than average (Niemi et al. 2009), although average temperatures in February-March were close to those of the reference period (1971–2000). Snow cover in the metropolitan area formed at the end of January and lasted until the end of March. In late March nighttime temperatures still dropped below zero and the last of the snow melt in mid-April. April was a dry month. There were somewhat more traction control measures done in the KAPU routes compared to the previous year. Street cleaning took place between mid-March and mid-April.

According to the maintenance records dust binding was widely used in Helsinki and Espoo. Dust binding in Helsinki is conducted according to the air quality preparedness plan in the whole city (twice in year 2009) and street-specifically or regionally at the supervisors' discretion. Dust binding measures in Helsinki were intensified during spring 2009. There were substantially more dust binding registrations compared to the previous years. Dust binding practices and their effects have been more profoundly discussed in Chapter 3.3.

According to meteorological data, winter season **2009/2010** was colder than average and with more abundant precipitation. Temperatures stayed below zero from December until the end of February. The Helsinki metropolitan area had a snow cover from the beginning of the year until late March. January and February in the metropolitan area were clearly colder than average. January was approximately 6–7 degrees colder than the reference period 1971-2000, and February more than 3 degrees colder. In late January the coldest temperatures measured in the Helsinki area were between -27.7 and -22.6 degrees. March was still colder than average, whereas April was warmer than average. Spring was rainy, which means that street surfaces did not stay dry for long periods and this may have reduced resuspension from the street surfaces. (Malkki et al. 2010),

3.1.2. Shares of different tyre types in 2007–2009

During the years 2008 and 2009 calculations of the shares of different tyre types were made in Helsinki. The aim was to find out at what point the switch from winter to summer tyres takes place. According to the graphs, it is estimated that the use of winter tyres decreases simultaneously while springtime street sweepings proceed and dust emissions decrease. (Fig. 1).

In Finland, the use of winter tyres is required between 1 December and 28 February. The use of studded winter tyres is allowed between 1 November and 31 March or until the first Monday after Easter, the latter day being determinative. The use of studded tyres is allowed outside the fixed dates if the weather or street surface conditions require so.

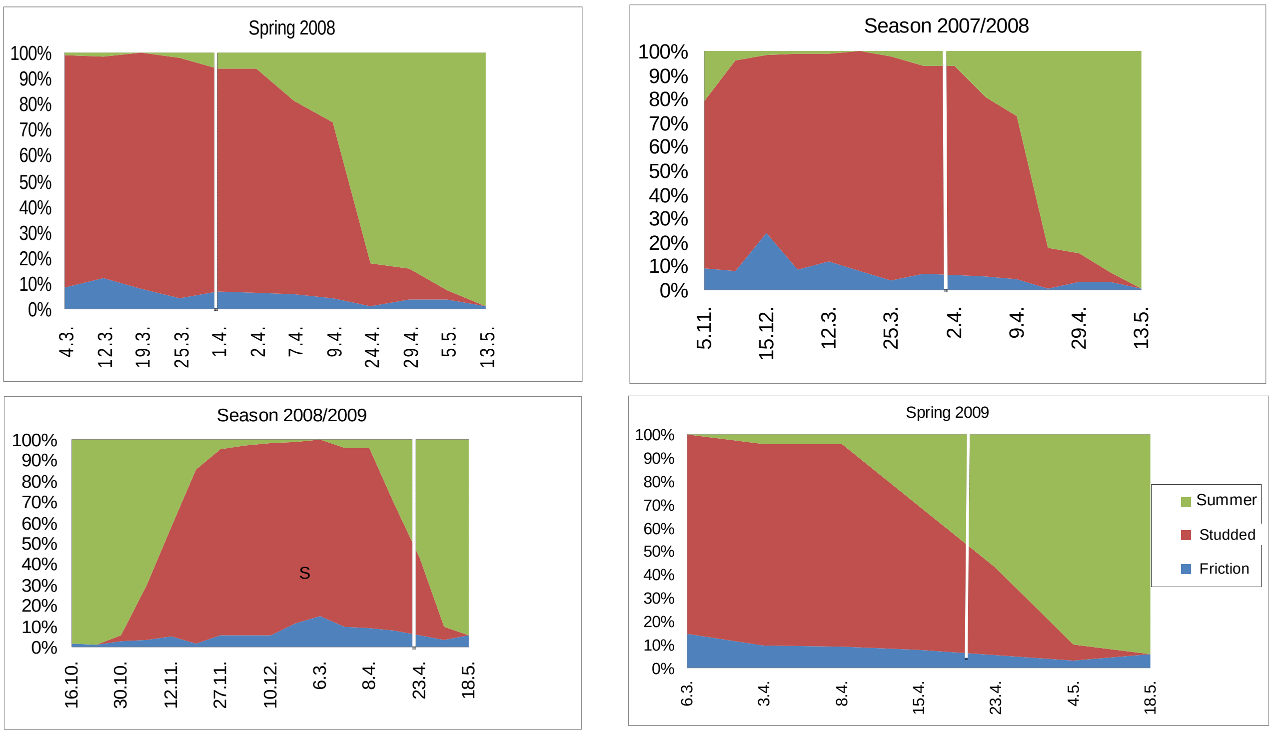


Figure 1. Calculations of the shares of different types of winter tyres and summer tyres in Helsinki. The white line indicates the last date after which studded tyres are not allowed to be used.

Particles that have been deposited on the road or in its vicinity during winter time may be re-suspended back into the air in the spring time. In the VIEME project (Tervahattu 2008) emissions from different tyre types were measured with the Sniffer mobile laboratory. The project's final report concluded that emissions from a summer tyre were always lower than emissions from winter tyres, i.e. friction- or studded tyres. When there was a lot of deposited dust on the street surface (Sniffer emission range 4 000 to > 20 000 µg/m^3), the emission from the friction tyre was equal or even higher than from a studded tyre. Whereas, when there was only a small amount of deposited dust on the surface of the road (<2000 µg/m^3), the emission from the studded tyre was consistently higher than with the friction tyre (see also Pirjola et al. 2010).

These results show that there are two main factors influencing the emissions measured behind a tyre: A) there is dust deposited on the road surface that is lifted, or re-suspended, by the tyre motion and B) the tyre wears the pavement and the wear products are emitted. In general, the emission from a friction tyre is dominated by resuspension, whereas the emission from a studded tyre consists of significant road wear as well as resuspension. If the road surface is loaded with a lot of deposited dust, the enhanced road wear by the tyre studs is masked by the resuspension. In the case of the tyres measured in VIEME, the friction tyre seemed to be more efficient in re-suspending the deposited dust in conditions with very high pavement dust loads. With lower resuspension levels the enhanced wear by the tyre studs became evident.

Observations indicate that the share of studded tyres is high during winter. A significant amount of winter tyres is still in use after the allowed dates. This might be due to weather conditions, but other factors may also affect the timing of the switch into summer tyres.

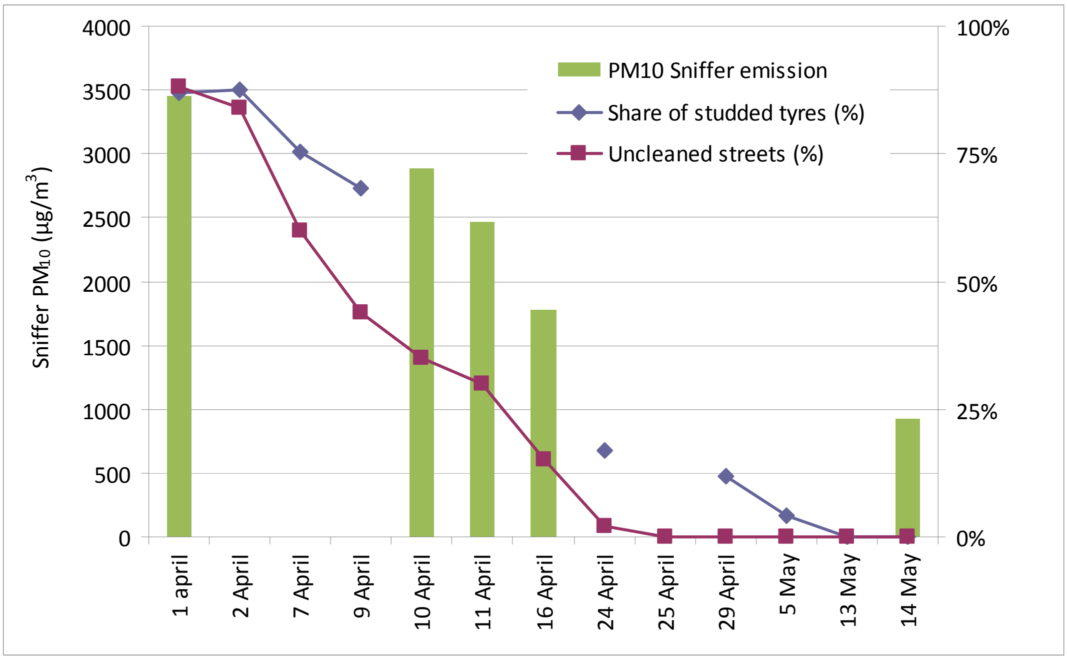


Figure 2. Average emission levels, share of winter tyres (%, rough calculations) and proceeding of the street cleaning in the Helsinki KAPU route in spring 2008.

3.2 Average emission levels in the KAPU routes measured by the Sniffer vehicle

Average Sniffer emission levels in the KAPU routes between mid-March and late May in years 2006–2010 are presented in Figures 3–10. The periods for dust binding and street cleaning are also presented. The KAPU routes are situated in different kinds of street environments and thus are not fully comparable with each other.

Street dust emissions have been highest between late March and early April (week 13–15). Year 2006 was exceptional as the spring arrived late, which caused the emission peaks to shift in Helsinki, Espoo and Vantaa. Average emission levels in the KAPU routes have varied between 4 000 µg/m^3 and 25 000 µg/m^3 depending on the city. After this the emissions have decreased steadily, and at the beginning of May emission levels in each city have in principal been on a relatively low level (Sniffer emission below 2 000 µg/m^3). Usually the very clean, summertime level (Sniffer emission below 1 000 µg/m^3) has been reached only after mid-May. Sniffer emission levels decrease simultaneously with street cleanings, but also with the decreasing number of studded tyres in use. Additionally there are often little or no dust deposits (snow, ice) left in the vicinity of the streets and little dust is released.

Dust may also be transported elsewhere from the street environment by atmospheric turbulences, rain and runoffs.

There are differences between the emission levels of different cities (note different scales in Figures 3–10.). All the KAPU cities are located in the southern part of Finland, but there is variation in the size of the cities, infrastructure, environment (for example inland vs. coastal areas) and weather conditions as well as in the winter maintenance practices. Information about the location and size of the cities is presented in Annex 1.

3.2.1 Observations from the KAPU cities

Figure 3 shows the average PM_{10} emissions in the Espoo route in 2006 to 2010. The peak PM_{10} emissions were observed in weeks 13–16 in Espoo route streets and there was large interannual variation from 2 000 µg/m^3 (2009) to approximately 10 000 µg/m^3 (2006). Reasons for the peak emissions in 2006 were extensive construction sites in the northern part of the route, which coincided with high emissions from winter maintenance. In 2006 and 2010 the peak emissions occurred later in spring, week 15 or 16 (17–23 April), compared with other years when the peak was weeks 13 or 14 (26 March–4 April). These were winters with relatively large amounts of snow and colder than average temperatures in March, which have postponed the release of deposited dust as well as postponed the beginning of extensive cleaning measures. A general phenomenon is that the emissions decrease steadily until May. In June the emissions in Espoo are on a clean summertime level (below 1 000 µg/m^3).

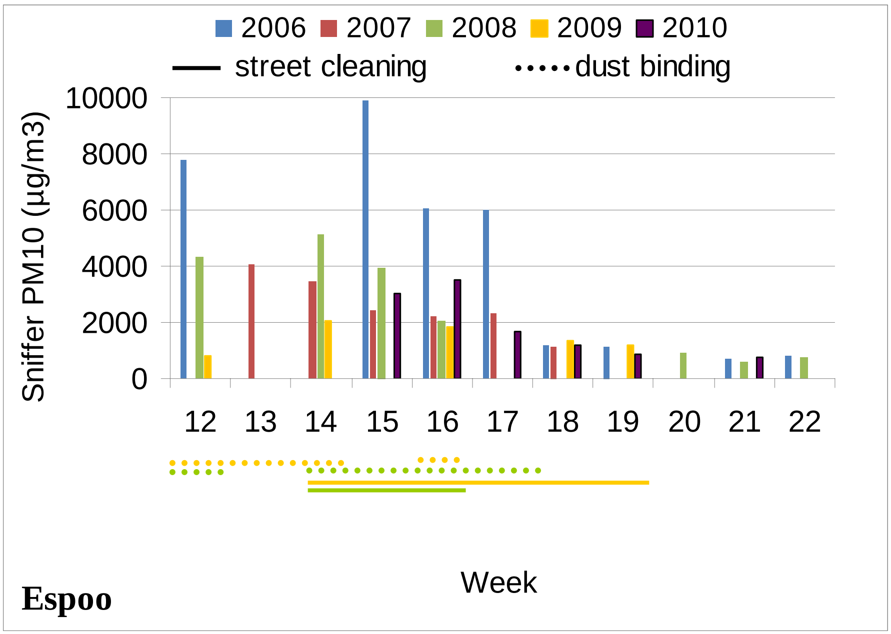


Figure 3. Average Sniffer emission levels in the Espoo KAPU route (µg/m^3) between mid-March and late May in 2006–2010.

In 2008 and 2009 cleanings were conducted also before the measurements. The data indicated that the street cleaning measures taken place in early spring (February–March) had no effect on the occurrence of peak emission levels. PM_{10} peak emissions in principal occur between late March and early April in spite of the preceding cleaning measures. This is a general phenomenon that has been observed in all cities. It is most likely due to the fact that street surfaces are still partly wet and/or snowy, a lot of dust has been deposited in the street environment and in spite of the street cleaning a lot of dust is still released from the deposits. More detailed information about the conditions and the amount of snow and ice in the vicinity of streets has not been available for this research.

In spring 2008 in Espoo, emission levels decreased significantly between 10 and 17 April. During the period dust suppressants were used in 11–12 April and 16–17 April and also street cleaning was performed on some of the streets. Additionally amount of precipitation was 7 mm. Dust can drift away from the street environment under different weather conditions. Rain and runoff waters cause the dust to be washed away, whereas airborne dust can drift away with turbulences. However, generally the rainfall does not explain the decrease in emissions in April. It can be assumed that the cleaning effect of rainfall depends on the amount of rainfall and formation of enough runoff waters to rinse the dust away from the streets efficiently. In general rainfall during April has been very scanty during the years of research, whereas May has generally been clearly more rainy than April (except in 2008).

Figure 4 shows the average PM_{10} emissions in the Vantaa route in 2006 to 2010. The peak PM_{10} emissions were observed in weeks 13–16 in Vantaa route streets and there was large interannual variation from 3 000 $\mu g/m^3$ (2009) to over 8 000 $\mu g/m^3$ (2006). Reasons for the peak emissions in 2006 were high emissions from winter maintenance practices after a harsh late winter. The peak emissions occurred similarly as in Espoo: in 2006 and 2010 the peak emissions occurred later in spring, on week 15 or 16 (17–23 April), compared with other years when the peak was on weeks 13 or 14 (26 March–4 April). The reason for this was the late winter weather conditions (see previous section).

Street cleaning practices have not always been noted to be directly proportional to the decreasing emission levels; however the street cleanings progressed simultaneously with decreasing emission levels week 16–20. During the KAPU project the Tikkurila route in Vantaa was used as a test area for intensified street cleaning activities with new equipment. Results from these measurements are discussed in Chapter 3.4. In June the streets in Vantaa had very low emissions, around 500 $\mu g/m^3$.

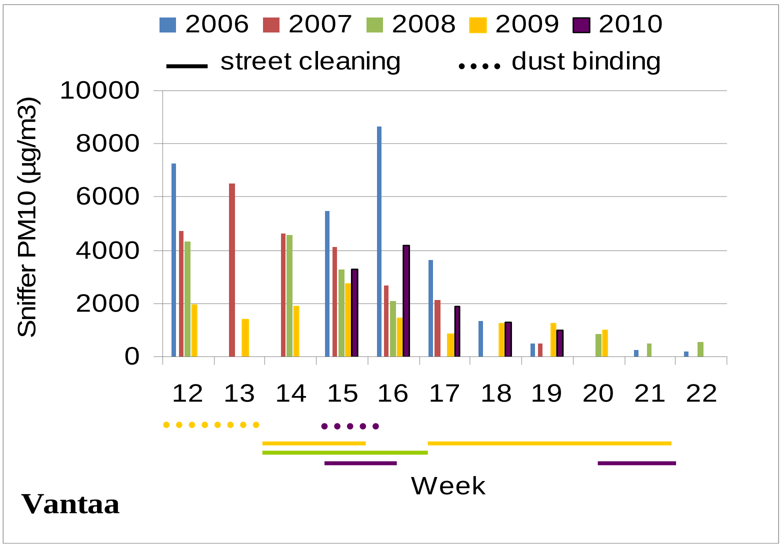


Figure 4. Average Sniffer emission levels in the Vantaa KAPU route (µg/m^3) between mid-March and late May in 2006–2010.

Figure 5 shows the average PM_{10} emissions on the Helsinki route in 2006 to 2010. The peak PM_{10} emissions were observed week 13–16 in the Helsinki route and the interannual variation was from 2 000 µg/m^3 (2009) to approximately 4 000 µg/m^3 (2006). Helsinki route peak emissions were relatively lower than in most of the other cities, although the Helsinki route is perhaps the most urban of them all and includes also street canyons. The city of Helsinki has paid a lot of attention to developing its winter maintenance practices, e.g. the quality and quantity of sanding material and the use of dust binding. No effect of the major construction sites that took place in Helsinki was apparent on the emissions on the Helsinki route.

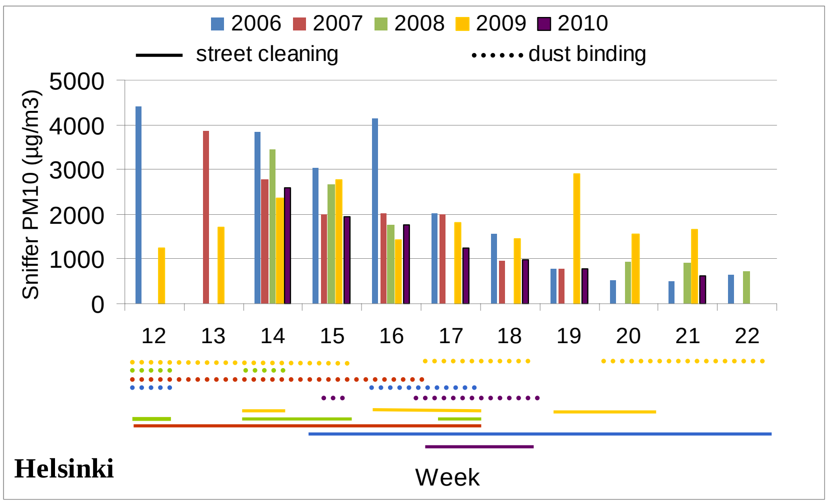


Figure 5. Average Sniffer emission levels in the Helsinki KAPU route (µg/m^3) between mid-March and late May in 2006–2010.

In the city centre of Helsinki, emission levels in street canyons were higher than the Helsinki route average. In late March and at the beginning of April when the emissions are usually high, emission levels in street canyons were above 5 000 µg/m^3. There is a lot of traffic in the Helsinki city centre and among it there is also heavy traffic and trams. Trams use traction sand on rails. Together with the closed environment this can affect the emission levels.

Aleksanterinkatu in the centre of Helsinki is an interesting research destination, since district heating pipes are situated below the pavement and they keep the street free of ice and also usually dry. Very little sanding or salting is needed, mostly they are used in the pedestrian areas. There is also very little vehicle traffic, apart from trams, because it is a shopping street and traffic is limited. Therefore it is expected that dust formation is low and that PM_{10} emission levels would be relatively low. However, results from Aleksanterinkatu tell a different story. Emission levels measured in Aleksanterinkatu in early spring have been the highest (approximately 10 000 µg/m^3 or above, in year 2006 approx. 16 000 µg/m^3) of the whole Helsinki route during the years of research. Because of the low amount of traffic in Aleksanterinkatu the use of studded tyres does not explain the high emissions. However, the traction sand used on tram rails might increase the dust load. Even if dust is not formed on site, it can be transported from somewhere nearby. For example Patra et al. (2008) have shown that PM_{10}-sized particles are transported efficiently in the street environment. They estimated in a study performed in London that the PM_{10} dust moved approximately 200 meters per hour in the direction of the vehicle traffic. Thus the dust from nearby streets can have an effect on street specific emissions, which might also be one explanatory factor in the Aleksanterinkatu case. An additional factor is that because of the heating, the street surface dries quickly and stays dry, and if the dust load transported from elsewhere is strong, the emission level might rise. Results indicate that it is worth paying special attention to the maintenance of heated streets.

Colder than average temperatures and abundant precipitation caused the winter season 2009/2010 to be challenging regarding the winter maintenance and traction control methods. For example in Helsinki, the number of traction sanding days was multiple compared to the preceding years. However the peak emissions in Helsinki were on a same level with the previous years (apart from 2006). The difference between 2006 and 2010 is partly explained by the further development and enhanced application of dust binding methods in Helsinki. Dust binding is discussed in more detail in Chapter 3.3.

The emission levels in Riihimäki during the KAPU project were higher than in the other cities, especially in early spring (Fig. 6). In 2007 emission levels in some individual streets were above 10 000 µg/m^3, even 50 000 µg/m^3, with a route average of 24 000 µg/m^3 (Fig. 6). Reasons for the high emission levels were estimated to be: (1) the only traction control method in Riihimäki is sanding, (2) even on a national scale extensive construction sites have been situated along the KAPU route and (3) there are lots of unpaved roads crossing the streets that belong to the KAPU route. These factors are especially emphasized in early spring, when dust deposited during winter is released back to the street environment. In 2009, after the construction works had finished, the peak emissions were lower than in other years.

In order to combat the dust problem rising from traction sanding, washed and sieved sanding material was deployed in Riihimäki during the KAPU project. The total amount of sanding material used during winter periods 2006–2007, 2007–2008 and 2008–2009 has stayed on relatively same level. In earlier studies, the fact that coarser sanding material (washed and sieved) decreases the formation dust, has been noted (Mustonen 1997, Kupiainen 2007).

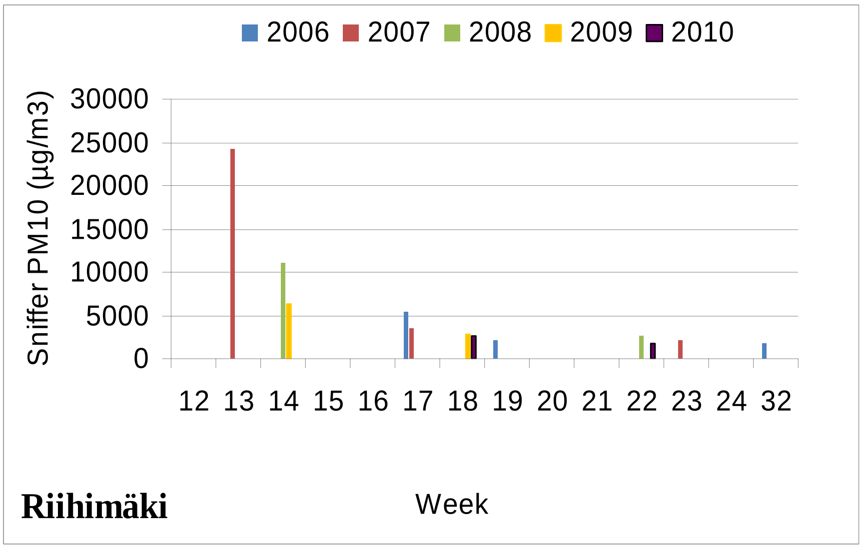


Figure 6. Average Sniffer emission levels in the Riihimäki KAPU route (µg/m^3) between mid-March and late May in 2006–2010.

Extensive construction projects started in Riihimäki at the end of 2006 and the beginning of year 2007. These construction sites in Riihimäki can be considered large even on a nationwide scale, and they affected the emission levels measured in the Riihimäki KAPU route especially in 2007 but some to some extent also during the subsequent years.

Porvoo joined the project late and measurements were conducted only in 2010. The emission levels in Porvoo in the early spring 2010 were on a very high level compared to the other cities, 8 000 µg/m^3 in Porvoo route (Fig. 7). Street cleanings took place throughout April, and by the beginning of June, the emission levels had decreased significantly. The high emission levels can be explained by the dust load from winter maintenance, construction sites as well as by the cobblestoned streets in the centre of Porvoo.

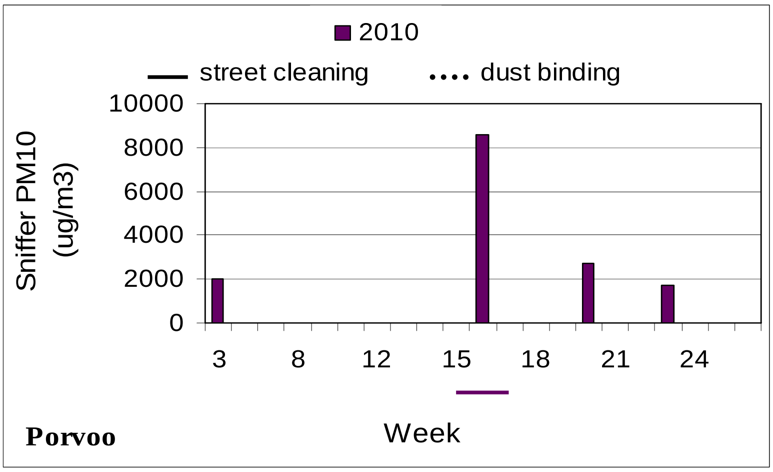


Figure 7. Average Sniffer emission levels in the Porvoo KAPU route (µg/m^3) between mid-March and late May in 2010.

Figure 8 shows the average PM_{10} emissions in the Tampere route in 2006 to 2010. Tampere joined the project late in 2006 and therefore the measurements in 2006 were conducted rather late, week 17 (last week of April). Tampere is located inland and was the most northern city in this study, approximately 150 km north of Helsinki. The peak PM_{10} emissions were observed week 14–16 in Tampere route streets, similarly as in other cities, and also in Tampere there was large interannual variation from 2 000 µg/m^3 (2009) to approximately 11 000 µg/m^3 (2008). However, Tampere route was not monitored as extensively as some of the other routes and it is possible that emissions in 2009 could have peaked later on. Street-specific variation is large spanning from approximately 3 000 µg/m^3 up to 15 000 µg/m^3.

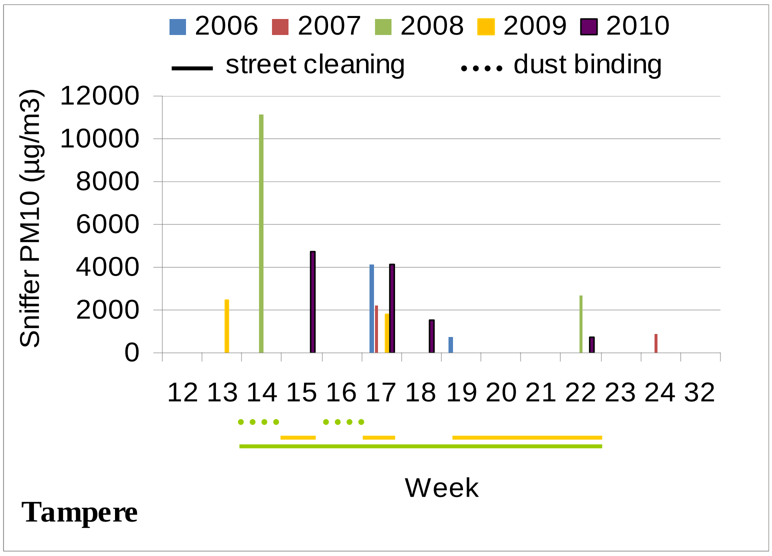


Figure 8. Average Sniffer PM_{10} emission levels in the Tampere KAPU route (µg/m^3) between mid-March and late May in 2006–2010.

Results from Tampere indicate that the amount of traffic alone does not explain high emission levels, although the use of studded tyres may cause increased dust formation compared to streets with less traffic. According to the results from the KAPU routes, it seems that there are many factors affecting the street-specific emission level, such as openness of the street environment, amount of traffic, amount of heavy traffic and winter maintenance practices.

Figure 9 shows the average PM_{10} emissions in the Turku route in 2008 and 2009. The peak PM_{10} emissions, 3 000 µg/m^3, were observed in 2008, week 14 (31 March–6 April). The emission level on the Turku route was one of the lowest in the participating cities.

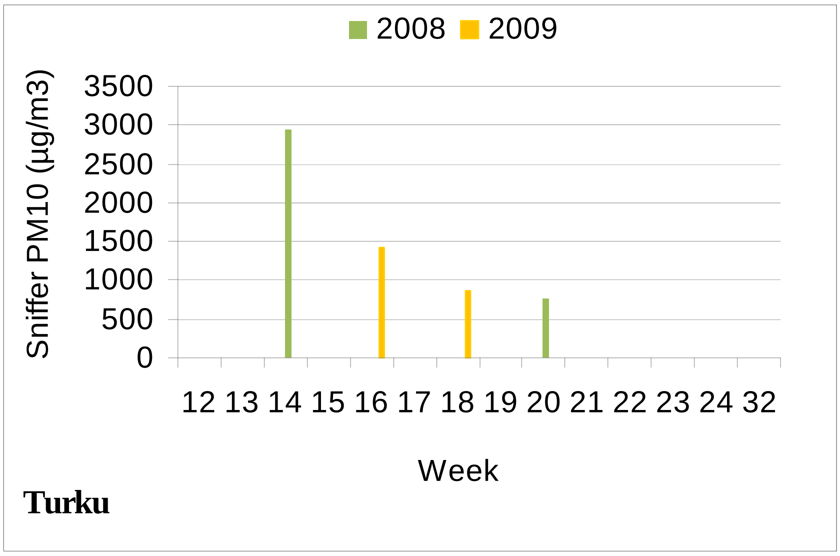


Figure 9. Average Sniffer emission levels in the Turku KAPU route (µg/m^3) between mid-March and late May in 2008 and 2009.

Figure 10 shows the average PM_{10} emissions in the Kerava route in 2006 to 2009. The peak PM_{10} emissions were observed week 14 (2008 and 2009, first week of April) in Kerava route streets. The peak emissions varied from 5 000 µg/m^3 (2009) to approximately 6 000 µg/m^3 (2008). The reductions in emission levels coincide with the street cleanings and at the end of spring emissions stabilize at approximately 1 000 µg/m^3. Noteworthy is that in 2007 there were also construction sites along the route, but the emissions were not significantly higher compared, e.g. with 2009 situation. During the construction works, the city introduced a management plan with extensive street washing around the sites.

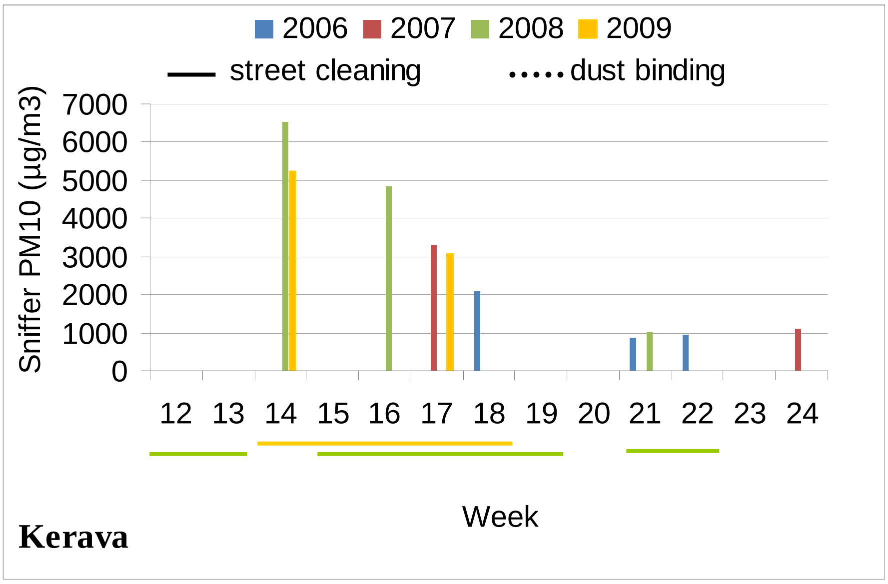


Figure 10. Average Sniffer emission levels in the Kerava KAPU route (µg/m^3) between mid-March and late May in 2006–2009.

3.2.2 Level of street cleanness

During the final phase of the KAPU project a step-wise index was designed to help demonstrating the city-specific results (Table 2). The aim of the index is to guide and help the work done by air quality and street maintenance managers to achieve better air quality in the springtime. The index would also provide a standard measure to compare the PM_{10} emission levels measured by different measuring vehicles. Further, presenting the step-wise results as index colors improves the visualization and readability of the results.

Table 2. Index table: index value, index color, Sniffer emission and description.

Index	Index color	Conc. (µg/m)	Definition
0–15		0–300	Wet or clean street surface.
15–50		300–1 000	Summertime clean street surface.
50–100		1 000–2 000	Street surface after springtime cleanings.
100–275		2 000–5 500	Actions required.
275–400		5 500–8 000	Actions required.
400–600		8 000–12 000	Actions required.
>600		>12 000	Actions required.

Based on five years of monitoring street surface emissions with the Sniffer vehicle, it was estimated that a Sniffer emission of 1 500–2 000 µg/m^3 (measured with a friction tyre, dry street surface conditions) might be a suitable standard for an emission level that would not lead to adverse air quality situations in normal weather conditions.

During the study period, this emission level usually prevailed in mid May or the end of May in the KAPU routes when all the extensive spring cleaning measures had also been finalized. This emission level was taken to be the threshold above which further actions are needed to lower the street surface emissions; the index value was set as 100.

Table 3 demonstrates the index-based results using the color scheme in the city of Porvoo. The values in the cells are the measured street-specific Sniffer emission averages. All KAPU routes, including the one in Porvoo, were designed by the air quality and street maintenance experts of the city and in the case of Porvoo the monitored streets were located in the city centre. The street or street section specific index demonstrates the overall emission situation during the measurement day. It pinpoints streets where active actions are required to lower emissions and it also helps to monitor how the situation has developed since the last measurement. Finally it demonstrates when no further actions are needed. The index approach was well received by the air quality and street maintenance experts and managers and it will be further developed in co-operation with them.

Table 3. Index-based results using the color scheme and corresponding Sniffer emissions in the Porvoo route in 2010.

Street	9-Apr-10	11-May-10	1-Jun-2010
Adlercreutzinkatu	9096	3982	2462
Aleksanterinkatu_P	7195	1538	1414
Jokikatu	16788		
Kaivokatu_P	8117	2786	1971
Kirkkokatu	4908	2748	1961
Kirkkotörmä	8291	3968	1850
Linnakatu	11955	3660	2330
Linnankoskenkatu	3665	2291	1431
Lukiokatu	15951	2979	3299
Läntinen Mannerheiminväylä	3908	905	680
Mauno Eerikinpojankatu	6953	4753	2160
Myllymäenkatu	11918	4518	3116
Papinkatu	5834	2409	1878
Piispankatu	14968	2320	857
Rihkamatie	3389	1427	738
Sibeliuksen bulevardi	3159	1260	727
Välikatu	9349	1854	848
City Average	8555	2712	1733

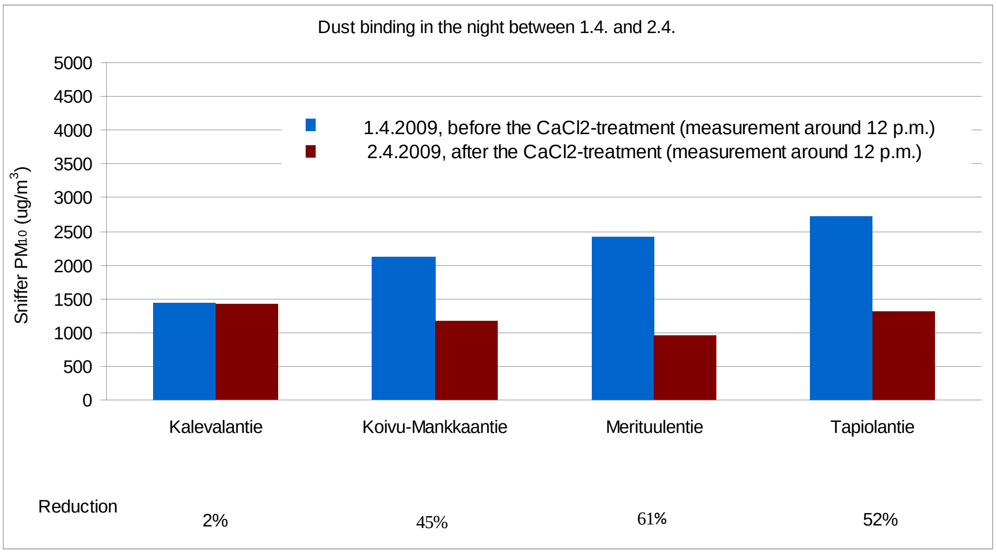
3.3 Efficacy of dust binding

Humidity causes the dust particles to agglomerate into larger entities and to adhere to the surface. Dust suppression with water is possible but it does not last long, only until the water evaporates from the surface. Evaporation can be slowed down by adding specific compounds to the water. In the Northern countries compounds such as calcium chloride ($CaCl_2$), magnesium chloride ($MgCl_2$) and calcium magnesium acetate (CMA) have been used for dust suppression. Dust binding agents also lower the freezing point of the liquid. Research studies show that dust binding reduces the amount of respirable dust. In Sweden both CMA and $MgCl_2$ have shown 20–40% reductions in PM_{10} concentrations (e.g. Johansson et al. 2005). Research done in Norway studied the effect of $MgCl_2$ on PM_{10} concentrations in a road tunnel (Aldrin, M. 2006). Concentrations dropped on an average by 45% and the effect lasted for 5–9 days. In Austria CMA has been shown to reduce PM_{10} concentration by 30% (diurnal average) in the street environment (Öttl & Hafner 2005). It was also estimated that by using CMA it would be possible to reduce the amount of exceedances of respirable dust limit values (diurnal averages) by 14 from 80/year.

In studies performed in the Nordic countries, it has been noted that efficient dust binding requires repetition and treatment of large areas. Gustafsson et al. (2010) compared the efficacy of dust binding solutions in the street environment using CMA (25%), $CaCl_2$ (10%), $MgCl_2$ (25%) and sugar (25%) Measurements by the road all showed 30–40 % reductions in PM_{10} concentrations straight after spreading. After that concentrations started rising slowly, and were back to the level before the treatment in 4–5 days. There were no differences between the efficacies or durations of different solutions. The dust binding ability of a solution depends on its concentration: stronger concentration has longer duration, but on the other hand it is more expensive and might cause slipperiness. Dust binding cannot conclusively solve the street dust problem as it does not remove the dust from the street, and there is a risk that the dust will be resuspended back into the ambient air.

In the KAPU project the efficacy of $CaCl_2$ as a dust binding agent was studied throughout the project. Use of dust binding has become a part of the winter maintenance practices in recent years in some of the participating cities. The findings on the efficacy of dust binding have been collected from the KAPU routes of these cities. The efficacy of $CaCl_2$ in dust binding was studied in Helsinki in the first phase of the KAPU project in March 2006. A 69% reduction in average emission levels in Helsinki was detected with Sniffer straight after the dispersion, whereas emission levels in the streets with no treatment showed no systematic decrease (Tervahattu et al. 2007). This effect was also visible in the Helsinki air quality monitoring data. Similar observations were achieved in Espoo in early April 2009 (Fig. 11). Emission levels decreased by ca. 40% on the treated streets, whereas no clear downward trend was detected on the streets left untreated.

Dust binding took place in the centre of Helsinki on 15 April 2010. Helsinki's KAPU route was measured in April 2010 before and after the dust binding (Fig. 12). First measurements after the treatment were conducted so that Kansakoulunkatu was measured on the same day the dust binding took place. Rest of the streets was measured 3 days after the dust binding. Additional measurement was conducted on 20 April to study the long term effect of the treatment



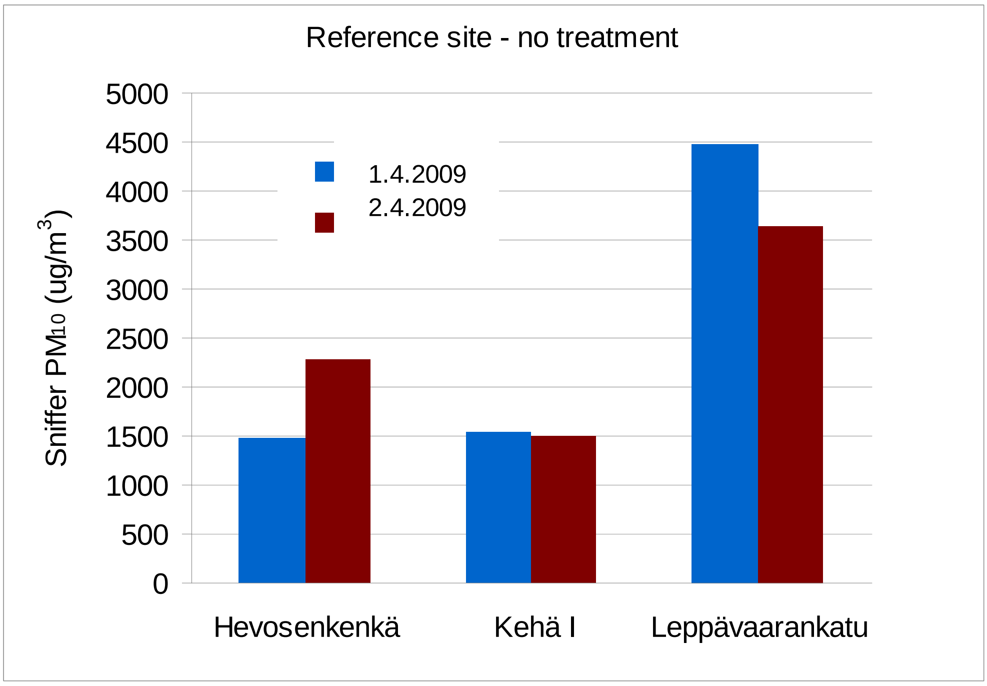


Figure 11. The effect of $CaCl_2$ dust binding on the emission levels in Espoo at the beginning of April 2009.

On an average the reduction in the PM_{10} concentration was 35% during the first measurement after the dust binding (Kansakoulunkatu 23%, Kaivokatu 45%, Kaisaniemenkatu 41%, Mannerheimintie 40%, Runeberginkatu 35%, Unioninkatu 32%). During the second measurement, 5 to 8 days after the treatment, some streets still showed lower emissions but some had similar or higher emissions. Therefore it was concluded that 5 days after the treatment dust binding efficacy has decreased and the treatments should be repeated to guarantee sufficient emission reduction.

The results from 2010 support the findings from earlier years as well as those from other studies: dust binding is effective in lowering the PM_{10} concentrations but that the reduction effect per treatment is limited in time.

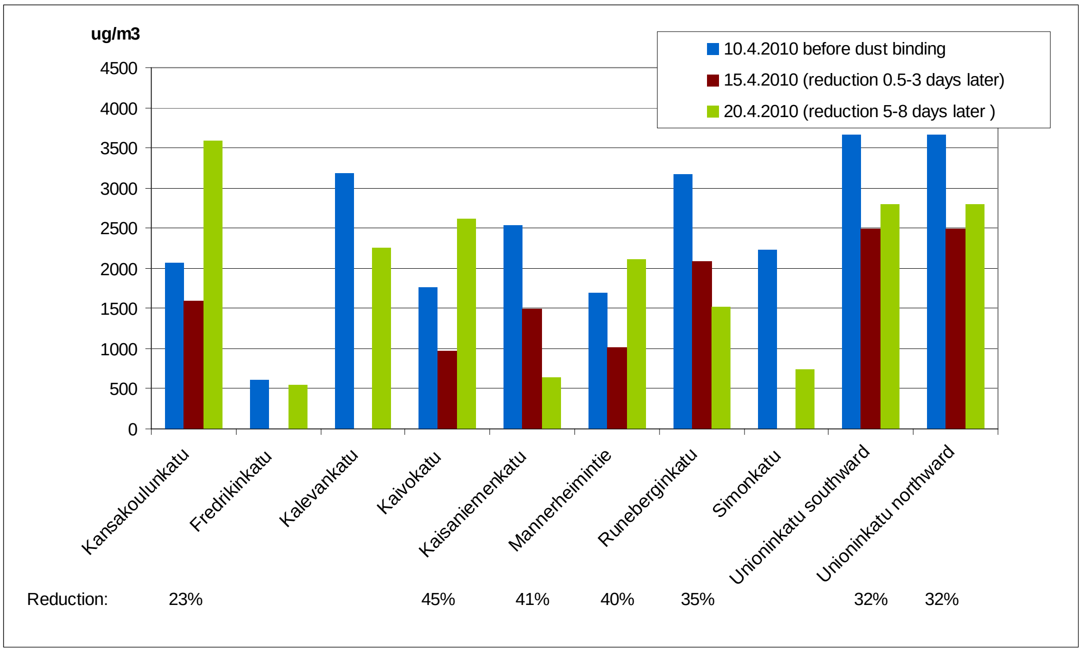


Figure 12. Dust binding in Helsinki in April 2010.

During the KAPU project, Espoo, Helsinki and Vantaa have harnessed special equipment for the dispersion of dust binding solutions. With this equipment it is possible to target the solution to specific, potentially problematic areas such as curbsides, gutters and in between the driving lanes (Fig. 13).

In spring 2009 Vantaa started using dust binding equipment, which is the result of city's own product development. The experiences were good. The equipment is easy and inexpensive to use as it is developed as an accessory part to the actual salt spreading equipment. Dispersion is done with an adjustable nozzle which can be directed to the left or right, and the operational width of the spray can be adjusted to different environments. According to the tests, the most appropriate concentration is 10% (mass volume percentages).

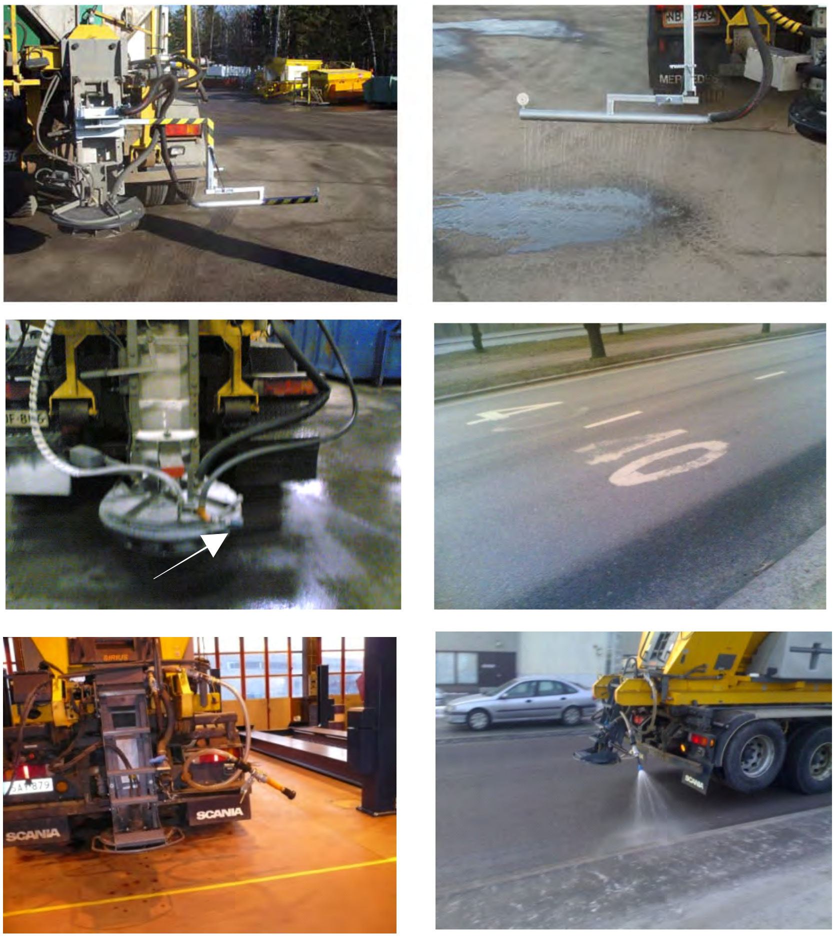


Figure 13. Special dust binding equipment used in Espoo (on top) Helsinki (in the middle) and Vantaa (below).

3.4 Street cleaning equipment

The equipment used for street cleaning can be divided into suction sweeping equipment and brush equipment (Mustonen 1997). Streets can also be washed with high pressure washing systems mounted on trucks.

The basic idea of traditional suction sweeping equipment is to moisten the material deposited on the street surface and with the help of brooms direct the material close to the nozzles which suck the material into containers. Suction is caused by blowers. Cleansed air can be directed either back to the blower or out of the system or back to the street surface (circulation of air). Moistening is a relevant part of the cleaning system in suction sweeping and thus the equipment can only be used in temperatures above freezing point. Moistening also silts up the fine particles so they do not clog or injure the blower. One of the disadvantages can be that the moisture traps the finest fraction of particles to the street surface and they can not be collected. Suction sweeping equipment is available in different sizes and technical specifications. Large sweeping machines (containers 5–6 m^3) are usually built on top of a truck. There is also equipment available that does not require moistening, but the challenge with the dry techniques is to prevent the dust from ending up outside the system and back into the ambient air.

Brushing equipment is also a common method to clean streets of visible debris. The operational principle is to use brooms to throw the debris into a container. The machines may have a suction system, but the amounts of air are significantly smaller than in suction sweeping machinery. Currently brushing is not used when surfaces are dry because it may cause dust emissions. Instead the streets are cleaned in moist conditions or they are moistened beforehand. Some brush equipment may include special moistening accessories.

High pressure street washing systems apply large amounts of water that is aimed at the street surface with nozzle systems. There are various types of equipment in use with different technical specifications. Typical factors that vary are the amount and alignment of the nozzles as well as the pressure and amount of water used during operation.

3.4.1 Studies of the efficiency of cleaning equipment in reducing respirable street dust particles

This section reviews the efficiency of street cleaning equipment in removing material from street surfaces. However, it is important to note that there are also other, equipment independent factors that affect the cleaning efficiency. Eventually, before starting a cleaning process, a management decision has to be made that chooses the right equipment for the location to be cleaned and that takes into account also the quality of the material to be removed as well as the properties of the target surface, such as porosity.

Studies reveal that current street cleaning equipment can efficiently remove visible sand and other material from the street surface but its reduction potential in the smaller fractions is poorer. Sutherland (2003) observed that 0.5–2-mm-sized loose material from the street surface was reduced by more than 80% due to suction sweeping, but smaller than 0.063-mm-sized particles only by 49%. From all the loose material on street surfaces, it is estimated that 10–15% belong to class 0.1 mm or smaller (Vaze & Chiew 2002). According to Bris et al. (1999) the concentration of loose material is highest on the side of the street next to the curbside, second highest on the street and lowest on the sidewalk. In Finland for example traction sanding affects the cross-sectional division of dust in the street environment and during winter also sidewalks may have large amounts of material.

So far the cleaning equipment has been designed to remove visible dirt and loose material efficiently and only lately more effort has been made to remove the smaller, respirable-sized fraction of street dust. The motivation for the recent emphasis on smaller dust sizes has mainly arisen from the air quality problems in various cities and more attention has been paid on the equipment's effect on the PM_{10}-sized particles. Studies show that there are major differences in the cleaning efficacy of different equipment. Gustafsson et al. (2007) have suggested that brushing has no effect on the concentrations of respirable dust, whereas suction sweeping and pressurized washing can reduce $PM_{10.}$

The efficiency of cleaning operations to reduce PM levels has been studied before and after the operation. The PM levels have been estimated by utilizing road side PM concentration measurement systems or mobile measurement systems that measure surface emissions. In the United States in the South Coast Air Quality Management District a system (RULE1186) has been developed to estimate the PM_{10} efficiency of cleaning equipment.

In the KAPU project the effect of pressurized washing system on the PM_{10} emission from the street surface was tested. It was noticed that the street section specific emission levels were 15–60% lower compared to the situation before the washing. The effect was found to be highest straight after treatment. In addition it was noticed that by increasing the pressure and the amount of water used, and optimizing the orientation of the nozzles it is possible to enhance the effect.

In the practical street cleaning work different types of equipment are often used together. For example in Helsinki in springtime all three; brushing, suction sweeping and pressurized washing are used side by side. In addition to the cleaning activities dust binding can also be used. In the first phase of the KAPU project (Tervahattu et al. 2007) street cleaning activities in Helsinki were noticed to be somewhat effective, but the effect did not last long, and only after 1–2 days the emission level had returned back to the level before the cleaning or even to a higher level. The further the spring evolved the longer the duration of the effect was. Reasons for the observed reduction in emission levels were listed to be the moistening of the surfaces, dust binding, and the removal of dust and loose material from the street environment.

Results show that the efficacy of cleaning is not only dependent on the efficiency of the cleaning equipment but also on the frequency of cleaning practices. The right amount of repetitions depends on the dust deposits and other sources of dust. In early spring there are still a lot of sources and dust is easily released, so the levels of dust emissions can easily return to the pre-cleaning level or even above that. It is important to note that with the practices studied in the KAPU project "summertime clean" surface could not be achieved with one single cleaning.

Norman & Johansson (2006) studied the effect of brushing and pressurized washing on the air quality in Stockholm, Sweden, and found out that brushing had no effect on the PM_{10} emission levels along the roadside. Concentrations on the study site were even higher than in the reference site. Pressurized washing on the other hand lowered the PM_{10} emission levels with 10% in some days, whereas in some days even higher emission levels were detected. The average reduction in PM_{10} emission level during 21 days was 6% and the number of exceedances of the air quality PM_{10} limit value was halved compared to the reference site. Researchers point out that the reduction in concentration can be partly due to the moistening effect of the washing more than to the actual removal of dust from the street.

In Berlin, Düring et al. (2004) detected on an average 6% reductions in diurnal PM_{10} levels on the days when pressurized washing system was used, but point out that the effect is not statistically significant. John et al. (2007) studied the effect of pressurized washing in Duisburg and noticed that it is possible to lower the diurnal PM_{10} levels with an average of 2–3 $\mu g/m^3$. Thus on the studied streets, with

optimized timing of pressurized washing, it would be possible to avoid 6–9% of the diurnal PM_{10} exceedance days (70–80 exceedance days in years 2004 and 2005).
Chow at al (1990), Kuhns et al. (2003) and Fitz (1998) have studied the efficiency of suction sweeping in the United States and noticed that cleaning did not have any effect on the PM_{10} concentrations measured by the road. However the results can not be used to draw conclusions concerning the whole range of equipment. According to researchers the equipment released finer dust into the ambient air. This leads to a conclusion that the suction or the protective installations have not been adequate. There might also have been defects in the filtering system of the outlet air. These aspects have been taken into consideration in designing new equipment, but still there can be big variation in the cleaning efficiencies of respirable size dust particles (Fitz & Bumiller 2000).

In Taiwan Chang et al. (2005) noted that the combination of washing and suction sweeping together lower the TSP concentrations measured next to the streets by 20–30%. First the concentrations rose but afterwards got lower and settled to a level that was approximately 70% from the pre-cleaning level. The effect of the cleaning measures lasted for 3–4 hours.

A combination of suction sweeping and dust binding with $MgCl_2$ (20%-solution, approx. 15 g/m^2) is used in Trondheim (Trondheim kommune & Statens vegvesen 2005). By this combination, depending on the location, 14-17 % reductions in PM_{10} diurnal averages have been achieved. Approximately 2% reductions have also been recorded for $PM_{2,5}$-sized particles. Cleaning measures have been conducted on dry surfaces, in night time (from approximately 2:30 a.m. onwards), since by then, most of the airborne particles have settled down on street surfaces. This reduction effect has been estimated to last at most 1–2 days depending on the meteorological conditions; wind, humidity and temperature. In Trondheim, dust binding may have had a strong effect on the downward trend in concentrations, so no single cleaning equipment can be identified to be behind the effect.

When evaluating the effectiveness of suction sweeping equipment, also the amount of dust in the outlet air has to be taken into consideration. In the existing equipment, the removal of residual dust from the outlet air is based for example on cyclone washes that remove the larger particles. Cleaning of the outlet air may also often be based on slowing down the air flow in the container, and letting the larger particles settle down at the bottom. Moistening of the air inside the container has also been tested; this method binds the smaller particles to the droplets. However these methods are not necessarily efficient in removing the respirable dust from the air flow.

New technical solutions in street cleaning are so called scrubbers, which combine high pressure washing with subsequent suction of the sludge formed during washing. A high pressure washing system removes dust and debris from the street surface, which together with the water form a liquid sludge, which is further removed from the surface into the machine by a strong suction. According to Schilling (2005) the result is a very clean street surface.

In the KAPU project's second phase, new techniques (Scrubber with Captive Hydrology, hereafter referred as PIMU) were tested for their ability to remove dust from the street. PIMU-tests were conducted before and after cleaning measures, so that detailed information about the efficiency and duration was achieved.

3.4.2 Use of PIMU (Scrubber with Captive Hydrology) in street cleaning - measurements in Tikkurila, Vantaa

The basic principle of PIMU (Scrubber with Captive Hydrology) is to use high pressure washing to release the loose material from the street surface to form sludge. Sludge is then sucked from the surface into a container. In Figure 14 a side view of the equipment owned by the city of Vantaa and Lakaisutekniikka is presented. In the middle of the machine there is also a wide suction nozzle, which makes the operational width slightly wider than the vehicle.

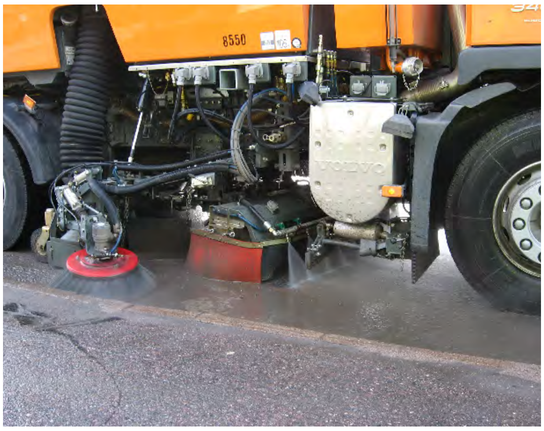


Figure 14. PIMU (Scrubber with Captive Hydrology) equipment owned by the city of Vantaa (on the left) and by Lakaisutekniikka (on the right)

In the early spring 2008 and 2009 street surface emission measurements were conducted with the Sniffer vehicle simultaneously with spring cleaning activities done with PIMU in Tikkurila, Vantaa. Measurements were conducted between late March and early April. The routes for the PIMU equipment, cleaned and uncleaned, are presented in Figure 15. In the spring 2008 the Tikkurila route was measured on four days before the cleaning measures and on three days after the measures. In the spring 2009 measurements were conducted during a longer period in accordance with the springtime cleaning activities. After the study, normal KAPU measurements were carried out in Tikkurila.

Average PM_{10} emission levels for cleaned and uncleaned streets in Tikkurila year 2008 are presented in Figure 16. Cleaning dates are also presented for the cleaned streets. According to maintenance records, salt was dispersed on the streets on 31 March after midnight due to night time frost. This might have had an effect on the emission levels on 31 March. According to the results, after the cleaning the emissions dropped on all cleaned streets, but on Talkootie and Talvikkitie which were left uncleaned, the emissions rose. The lower emission level measured on 31

March might be due to the dust binding effect of salting, which was conducted for traction control purposes.

Figure 15. The red line indicates the Sniffer route, cleaned by the PIMU equipment. The dashed line indicates the part of the route that was left uncleaned.

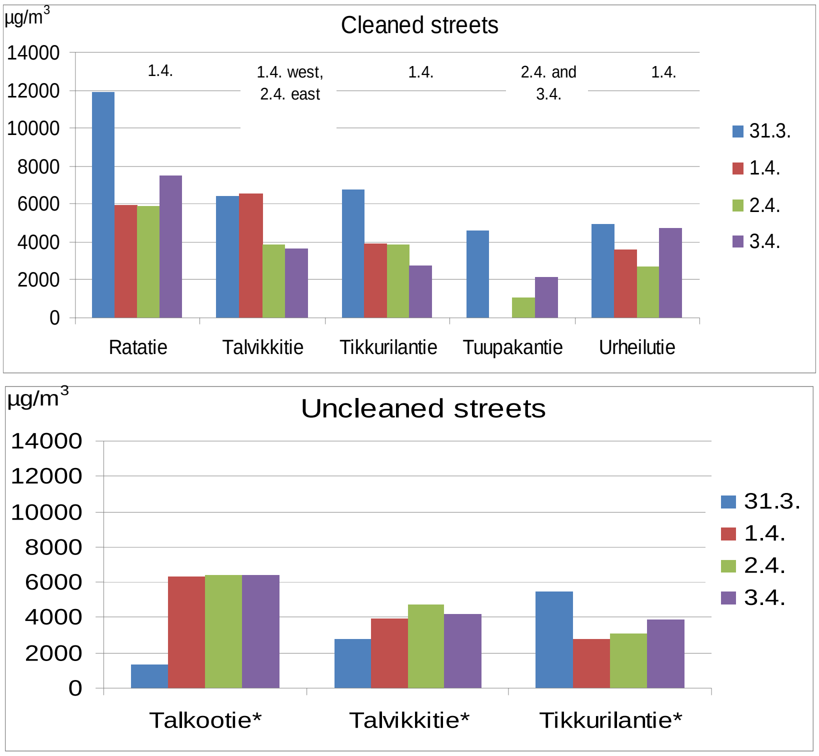
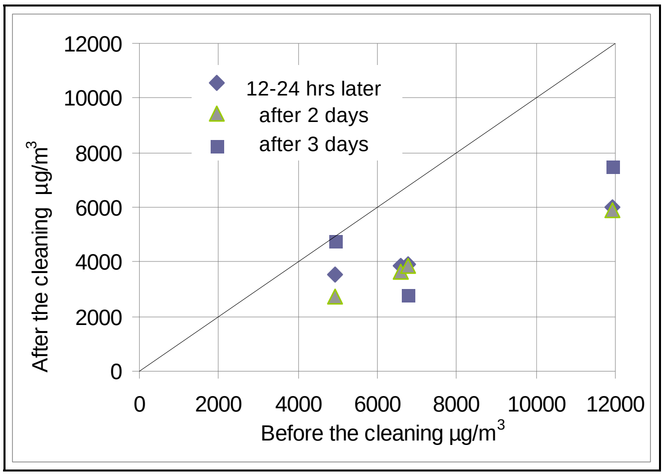


Figure 16. Average PM_{10} emissions in cleaned and uncleaned street section, and the cleaning date for the cleaned street sections in Vantaa 2008.

As a result of the cleaning activities, the PM_{10} emission level was halved compared to the situation before the cleaning, and remained approximately constant for several days (Fig. 17.). This gives a reason to suppose that the decline in the emission level was not due to the moistening but to the cleaning. However, the emission levels did not drop down to the summertime level (approximately 500 to 1 000 ug/m^3).

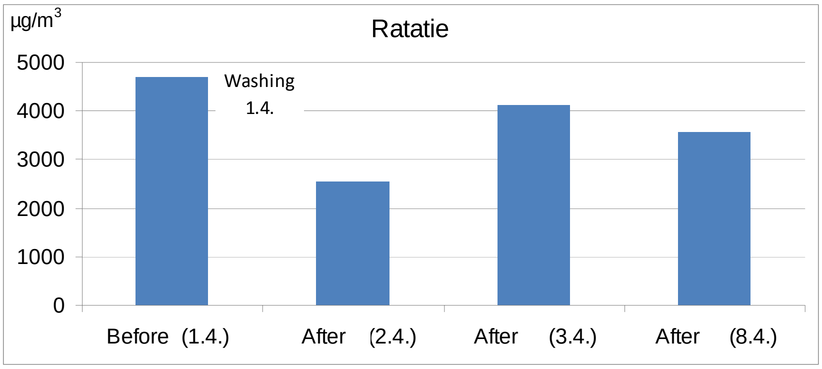


	Reduction in concentration		
	Day 1	Day 2	Day 3
Ratatie	50%	51%	37%
Talvikkitie	42%	45%	
Tikkurilantie	42%	43%	59%
Urheilutie	28%	45%	4%

Figure 17. Average PM_{10} emission levels in the spring 2008 before and after the cleaning and the relative changes in Sniffer emissions (%).

In 2009 some of the streets had already been cleaned with mechanical broom sweepers and suction sweepers at the beginning of March, before the study period. Also the cleaning activities and measurements had to be conducted during a longer period of time (1–8 April 2009) than previous year due to weather conditions. The PM_{10} emission level in Tikkurila in general was lower in 2009 than in 2008. In Figures 18 and 19 the average emission levels in the measured streets in Tikkurila in 2009 are presented. For the cleaned streets, cleaning dates are also presented. Results from Ratatie are presented in a separate graph, since it was cleaned before the other streets (Fig. 18, on top).

In all cleaned streets, except Kielotie, emissions had dropped due to the cleaning activities. At the same time, the emission level in the uncleaned section of Tikkurilantie showed no significant decline. However, the emission reductions due to cleaning with the PIMU equipment were not as large and did not last as long as in 2008 (Fig. 16). The most important factor explaining the difference between the two years is likely the generally lower emission level in spring 2009, compared to 2008. For example the PM_{10} emission level in Ratatie before the measurements in year 2009 was 60% lower compared to the pre-cleaning level in 2008. In the other streets the general emission level was 2 000 µg/m^3 or lower, a level which is usually detected in late spring after large scale spring cleanings.



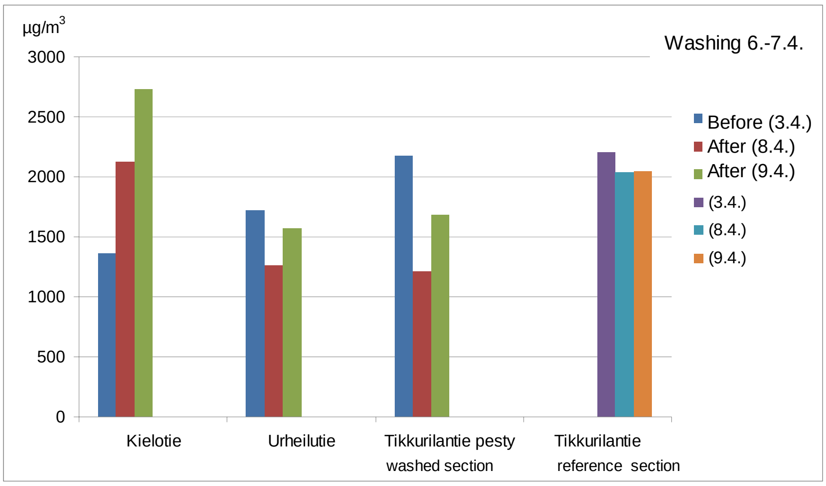


Figure 18. Average PM_{10} emissions in cleaned and uncleaned street sections in Tikkurila, Vantaa 2009.

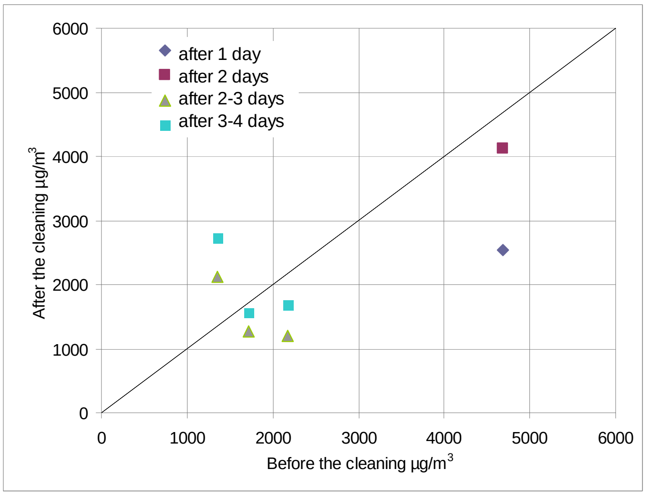


Figure 19. Average PM_{10} emission levels in spring 2009 before and after cleaning and corresponding relative changes in the Sniffer emission (%). A negative result means that the emission has increased.

The results indicate that it is possible to reduce PM_{10} street surface emissions with the PIMU equipment, but the reductions in emissions during low initial emission levels are not relatively as large as with higher initial emission levels. According to the results, with emissions lower and higher than 5 000 µg/m^3 the respective average reductions were approximately 30% and over 40%. However, there are no efficiency measurements from Tikkurila for pre-cleaning emission levels 1 500–2 000 µg/m^3 (late spring emissions). Emissions a few days after the cleaning had a large range depending on the street.

The range of street-specific emission values was between approximately 2 500 to 6 000 µg/m^3 in 2008 and 1 500 to 4 000 µg/m^3 in 2009. Considering the emissions observed in the participating cities, the lower range can be considered already a relatively clean surface, but the higher range not. Therefore we conclude that one cleaning alone does not necessarily reduce the emissions sufficiently and one should be prepared to repeat the cleanings at least on some streets. Three days after the cleaning the lowest emission levels observed were approximately 2 000 µg/m^3, which is still more than twice the summertime emissions.

3.4.3. Filtering of outlet air

In order to minimize the respirable dust in the outlet air, aerosol filters (e.g. cyclone, fiber and electrical filters) are being developed for the cleaning equipment. Theoretically with this kind of equipment it is possible to achieve even 90% cleaning efficiency in the outlet air respirable dust concentrations. Often these solutions occupy a lot of space and increase the size of cleaning equipment as well as the price.

Tests were conducted in Viikintie Helsinki to measure the dust load in the outlet air of Dulevo cleaning equipment. The Dulevo equipment tested (Dulevo 5000) were mechanical sweepers that apply suction. This equipment uses less air than suction equipment, which means that there is enough room in the machine for a filtering system. Dulevo has developed an advanced filtering system (Gore) for their equipment, which was tested during the KAPU project.

First measurements were conducted in August 2008 when street surfaces were on a relatively clean summertime level (Fig. 20). Sand was spread on one section of Viikintie, on the road side (Fig. 20: 1_west) in order to gain knowledge from dustier circumstances. A standard filter was compared with the advanced Gore-filter. Same filters have been tested earlier by Det Norske Veritas. The results from Viikintie measurements showed slightly higher reductions in the emission levels, but the emission levels were all in all of the same magnitude. The particle concentrations with the Gore filtering system were approximately half of the ones measured with the standard filtering system.

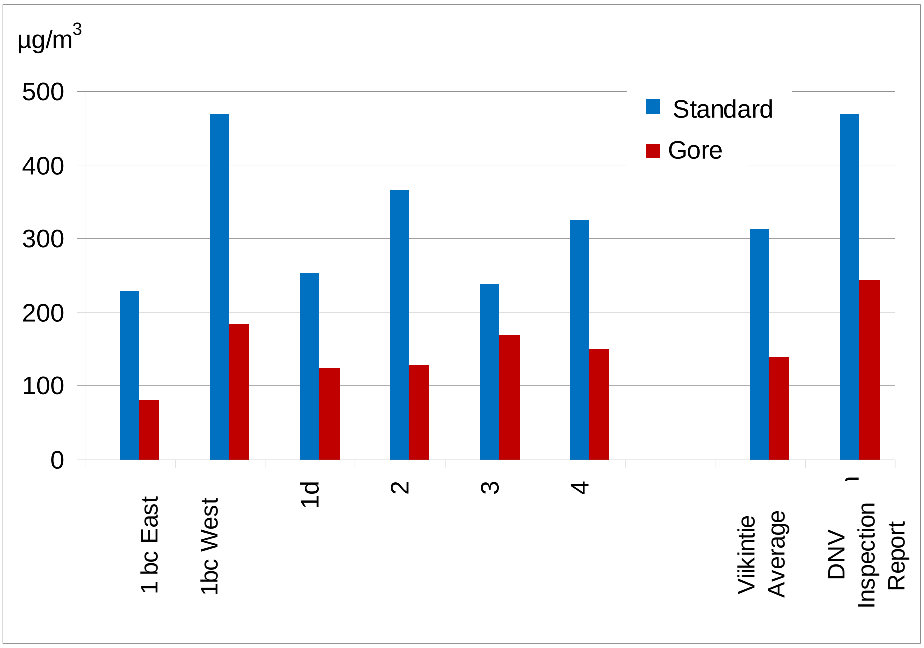


Figure 20. Average PM_{10} emission levels of the outlet air in August 2008 in Viikintie (street sections 1–4) for standard and Gore filters.

The second set of measurements of the Dulevo equipment was conducted in early April 2009. The aim was to repeat the measurements done in 2008 but during the springtime dust period, with much higher dust loads. The PM_{10} emission level in 2009 tests was approximately quintuple compared to the situation in August 2008.

Results of the dust level in the outlet air for different street sections are presented in Figure 21. In 2009, the PM_{10} concentration levels in the outlet air with a standard filter were on an average sevenfold compared to the concentrations in 2008, whereas the Gore filtering system had approximately the same level as in 2008.

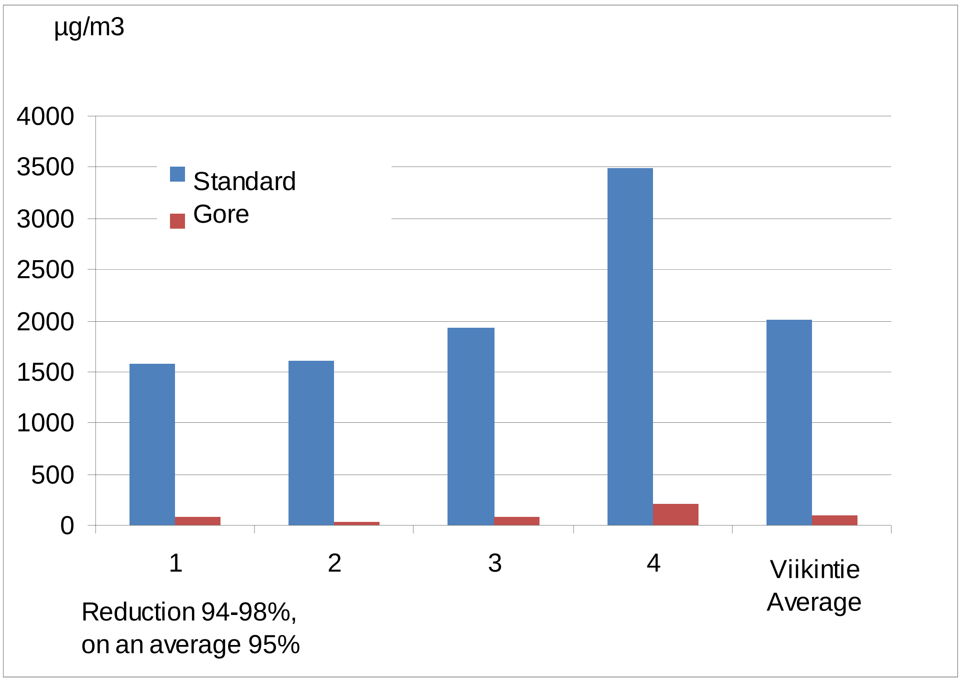


Figure 21. Average PM_{10} emission levels of the outlet air in April 2009 in Viikintie (street sections 1–4) for standard and Gore filters.

Based on the results from both years, it looks like with the advanced Gore filtering system it is possible to achieve significant reductions in the outlet air PM_{10} concentrations and thus mitigate the negative impact on air quality during cleaning activities. However, these results apply only to the Dulevo equipment and further measurements should aim at studying the outlet air concentrations with other equipment as well.

3.5 Dust load from construction sites in Riihimäki

During the KAPU project, extensive construction works took place along the KAPU route in Riihimäki between late 2006 and the beginning of 2007. On some sites operations lasted until spring 2009. These construction sites had an effect especially in the southeastern part of Riihimäki's KAPU route (Fig. 22). The streets in the southeastern part of the route (Eteläinen and Pohjoinen Asemakatu, Kulmalan puistotie, Etelän Viertotie) were in the immediate vicinity of the construction sites, but the dust spread elsewhere mostly because of traffic thus affecting a larger area.

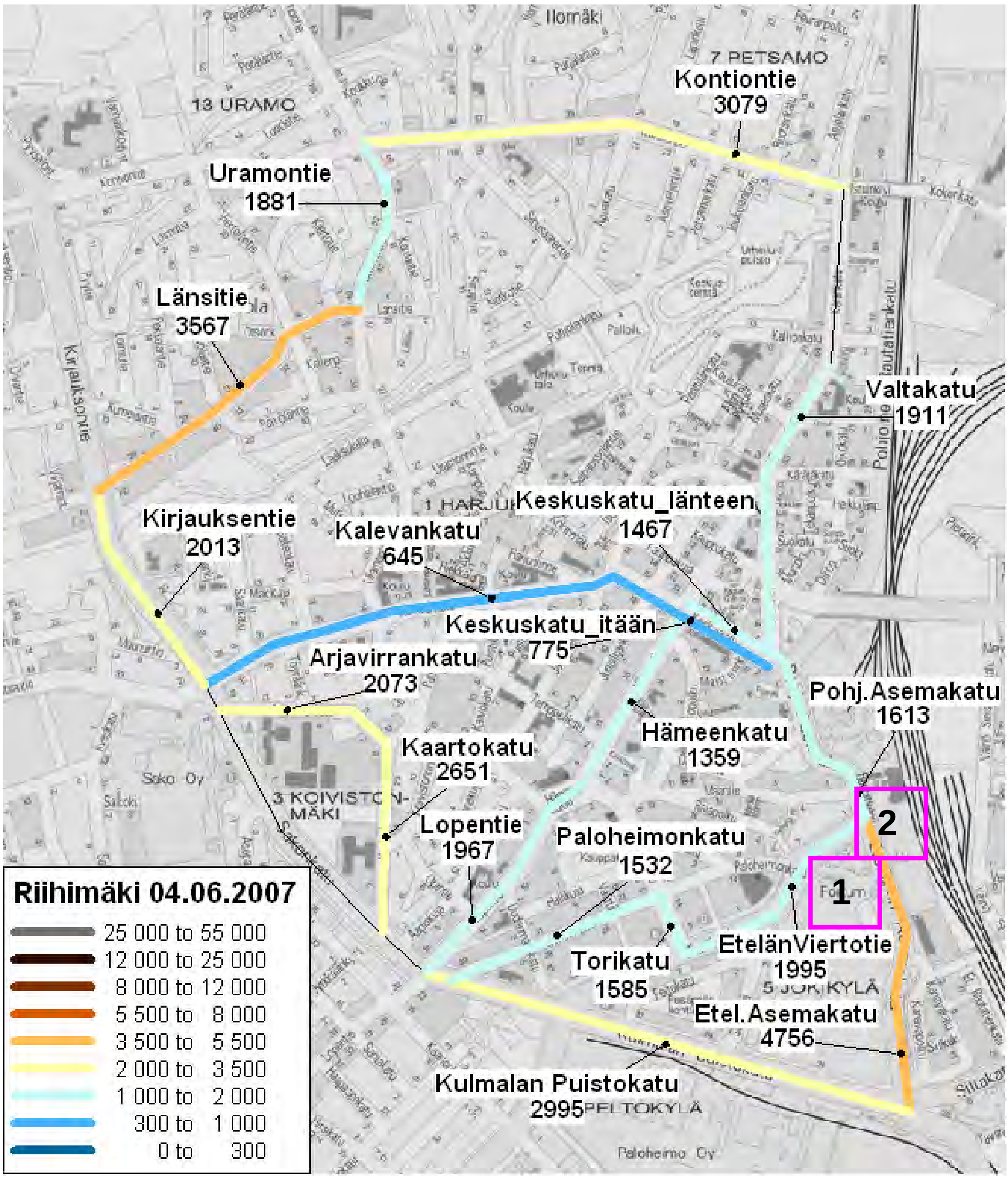


Figure 22. Street-specific PM_{10} emission levels in Riihimäki along the KAPU route on 4. June 2007. Wide construction sites were ongoing in the southeastern part of the route: 1) Atomi-commercial centre (under construction between August 2006–November 2008) 2) Travel centre (under construction between March 2007–March 2009).

In summer 2007, the emission levels in Riihimäki were relatively high especially near the construction sites (see Figure 22: Etel. and Pohj. Asemakatu, Etelän viertotie; and Fig. 23). Wide unpaved areas, simultaneous construction-related traffic, and dust generating construction work increased the emission level also in the nearby streets. The high emission level in Kaartokatu/Arjavirrankatu in 2007 (see Fig. 22) is likely due to a wide unpaved temporary parking lot nearby. In the northern part of Riihimäki's measurement route, there are unpaved streets crossing the route, and it was observed that some dust is spread on the route from these unpaved streets especially close to the crossings (see Fig. 22: Kontiontie, Länsitie, Uramontie and Fig. 23).

In summer 2008 there were still wide construction works along Riihimäki's KAPU route. Emissions were on a very high level and varied between ca. 5 000 and 23 000 µg/m^3 in the streets which are situated close to the construction sites. Different lanes and driving directions were also compared, and it was clearly noted that dust was transported from the adjacent streets all the way to the nearby streets by the traffic from the construction site as well as vehicles passing by.

In summer 2009, when the construction works had finished, the emission levels were no longer elevated on the streets that in 2007 and 2008 were under the influence of the large construction works. The results show that it is worth paying attention to the dust dispersed from the construction sites. Construction sites affect the emission levels especially in nearby streets. Large construction sites, as in Riihimäki, tend to have this effect in wider areas. The effect is especially substantial in summertime when the springtime street dust levels have already decreased. Dust emissions from construction sites depend on the type of constructing, how much dust is spread around by construction traffic, and what kind of cleaning measures are required to be performed in the construction site.

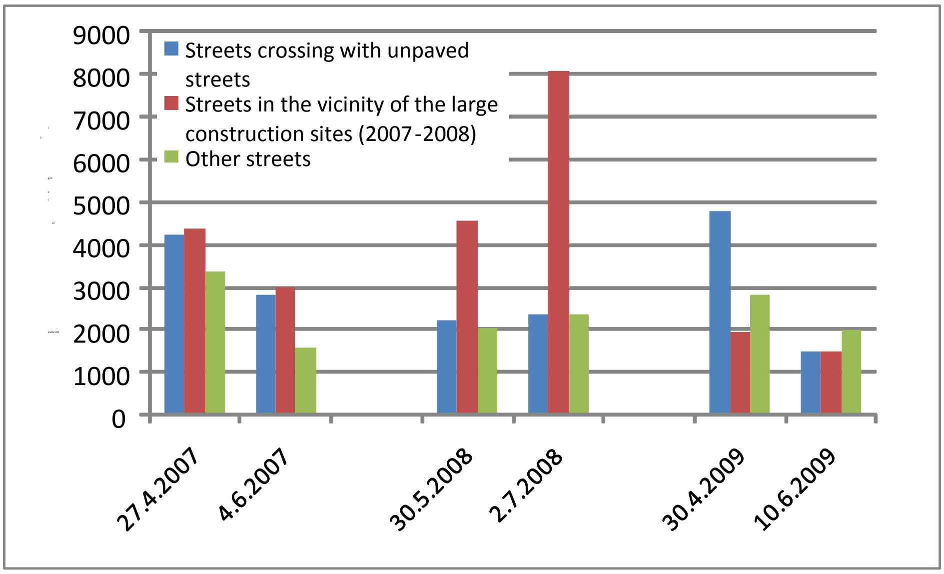


Figure 23. The streets of the Riihimäki KAPU route divided into groups by their location and surrounding circumstances.

3.6 Winter maintenance and traction control practices for dust emission mitigation

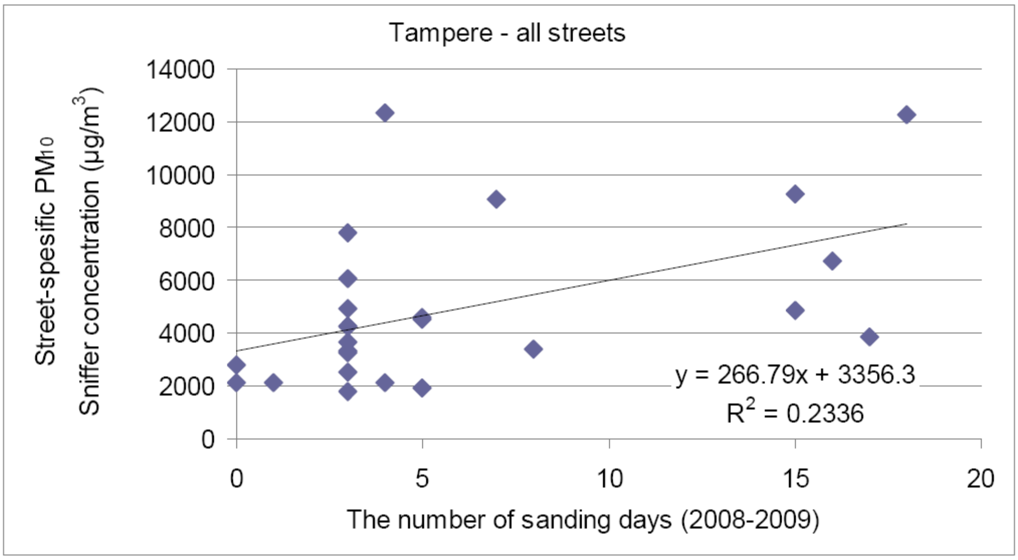
One of the goals of the KAPU project was to find out the possibilities of winter maintenance practices (ploughing, snow removal, traction control) in the prevention of springtime dust episodes.

Ploughing and removal of snow from the streets have been discussed in the impact assessment of Helsinki's air protection plan. (Kupiainen & Tervahattu 2007c, Viinanen 2008)) Some conclusions from the report:

- The exact amount of dust deposited among ice and snow in urban areas is not known, especially for respirable dust.
- Samples taken from the city centre may have 15–20-fold concentrations of solid material (1 000–1 900 mg/l) compared to the concentrations of pristine snow samples from urban areas (66–90 mg/l) ((Kotola & Nurminen 2003a, 2003b). Solid material concentrations are lower outside urban areas.
- Traffic density affects the amount of solid material. In a study conducted in Luleå, Sweden, it was found out that the amount of solids was approximately double (1972 mg/l) when comparing a street with heavy traffic (KVL 20 000) to a street with less traffic (876 mg/l) (KVL 4 500) (Kotola & Nurminen 2003a)
- In urban areas the springtime runoff resulting from melting snow can form a large part of the solid material of the yearly storm water runoff. (Kotola & Nurminen 2003a, 2003b)
- Ploughing and removal of snow can help to remove and relocate the deposited solids to areas that are less sensitive to dust.
- Along with the removed snow, a lot of potentially dirty and dusty material is removed from the street environment.

During the project, an extensive amount of data about traction control methods (salting and sanding) was collected from the participating cities. The immediate response of traction control methods to the formation of dust was not studied in this project. Earlier studies show that sanding increases the formation of dust and the emissions, and that it is possible to reduce the formation of dust by choosing appropriate sanding materials.

Street-specific information from Helsinki and Tampere about the amount of traction control methods was collected within the KAPU project, and this information was compared with the springtime maximum emission levels. The interconnection between the number of sanding days and the maximum emissions in all streets in both cities are presented in Figure 24. There is some dispersion between streets, but all in all the results point out that with an increasing number of sanding days the emissions also tend to be on a higher level. With a lower number of sanding days, an average emission of 3 000 μg/m^3 was detected, whereas with greater number of sanding days, the average emission was approximately doubled. In Tampere, the emission level increased more intensively in relation to the number of sanding days. Differences between the cities can be caused by e.g. different sanding material. In Tampere unwashed crushed rock is used, whereas in Helsinki, washed and sieved 1–6 mm rubble is in use.



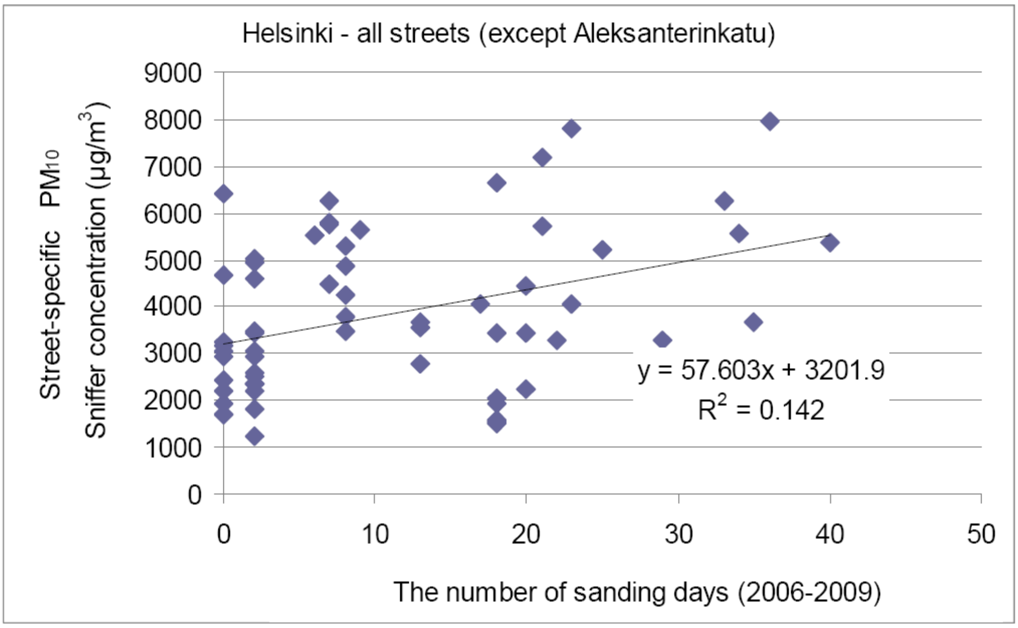


Figure 24. The number of sanding days in the KAPU route in relation to springtime maximum emissions in Tampere (2008 and 2009) and in Helsinki (2006–2009).

In Helsinki, the data was furthermore divided between different street environments (semi-open street environment and street canyons). In street canyons and semi-open street environments an increasing number of sanding days also meant a higher level of maximum emissions (Fig. 25). In street canyons the emission level was somewhat higher than in semi-open street environments. Measurements were also conducted in open street environments but the linkage between the number of sanding days and the emission levels was not as distinct, which can at least partly be due to better dispersion conditions.

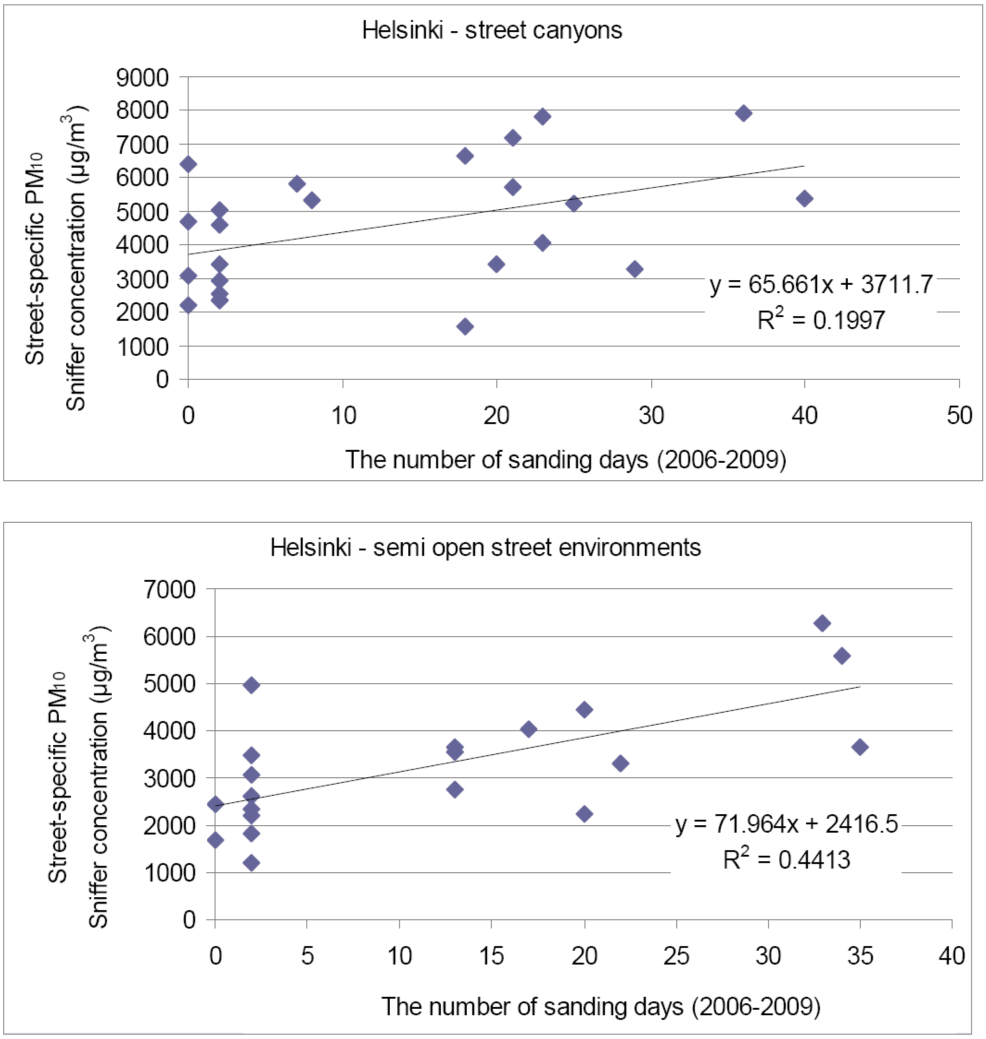
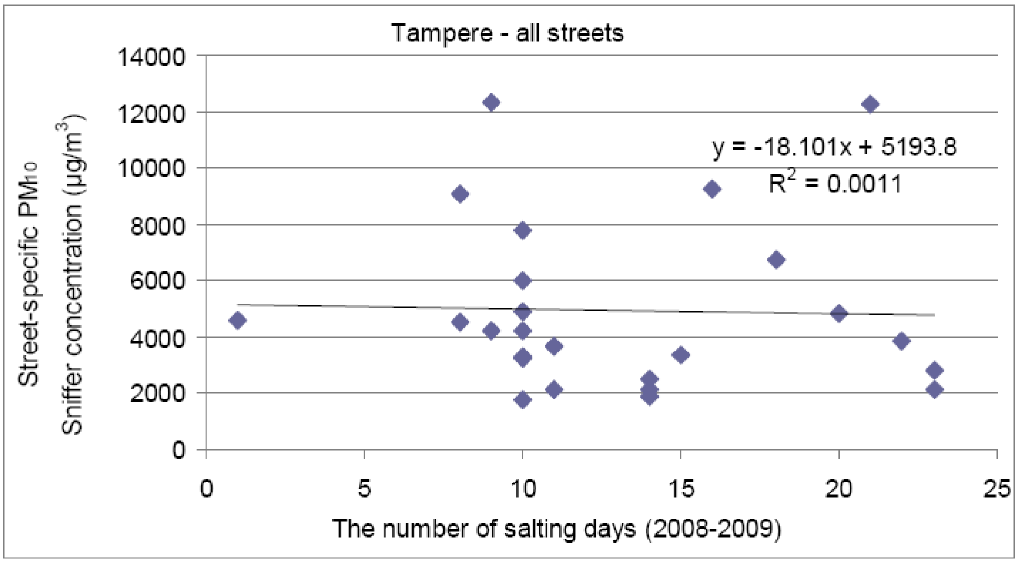


Figure 25. The number of sanding days in the KAPU route in relation to springtime maximum emissions in Helsinki (2006–2009 data): in street canyons and semi-open street environments.

Respectively, the correlation between the number of salting days and the springtime maximum emission levels in the Tampere and Helsinki KAPU routes are presented in Figures 26 and 27. The correlation between the emissions and the number of salting days is inverted compared to the correlation between the emissions and the number of sanding days.



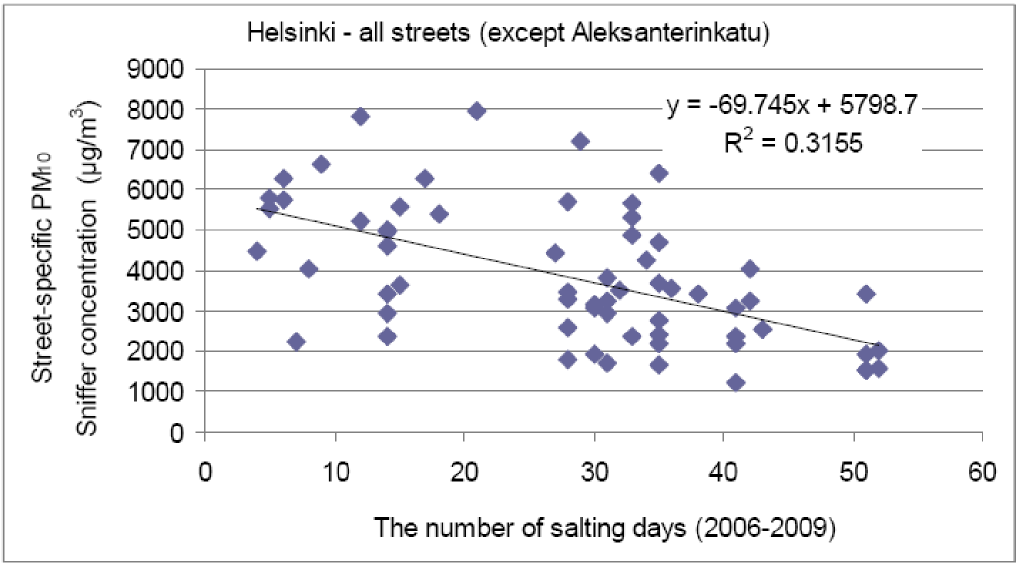
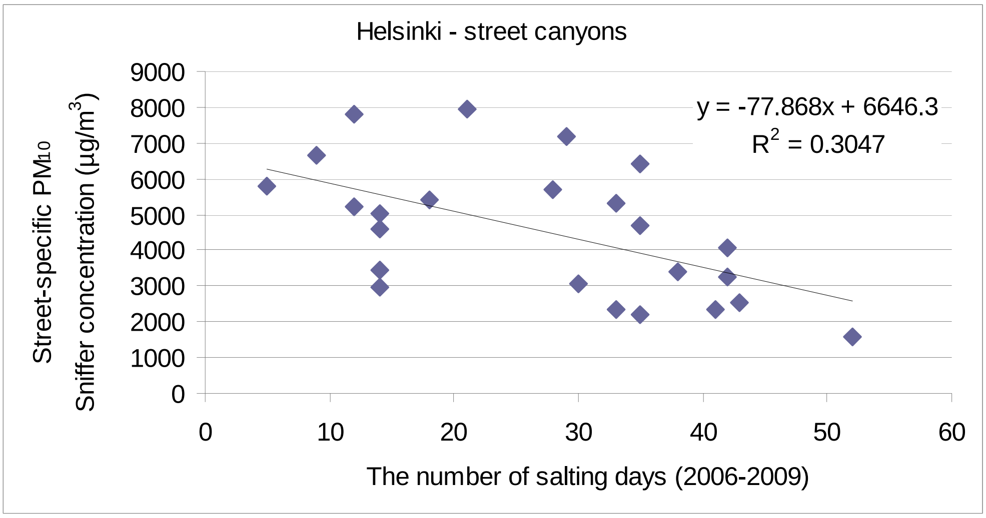


Figure 26. The number of salting days in the KAPU route in relation to springtime maximum emissions in Tampere (2008 and 2009 data) and in Helsinki (2006–2009 data).

The comparison between the number of sanding/salting days and the emission levels indicates that the higher the amount and frequency of sanding, the higher the emissions. And on the contrary, with an increasing amount of salting, lower emissions have been detected, since depending on the winter conditions these two methods are alternative traction control tools in the studied cities.

There is some variation between streets, but also other winter maintenance methods such as ploughing and sanding of the footpaths, can be assumed to have an effect on the street-specific emissions. Winter conditions also vary between different years and this may affect for example the amount of snowfall and deposits, and thus the amount of dust deposited in the vicinity of the streets. This data supports the conclusion that sanding has an increasing effect on the street dust emission levels, and by substituting sanding it is possible to decrease the amount of dust. In this context, it is also worth noting, that in Finland the utilization degree of studded tyres is very high. Approximately 90% of all passenger cars use studded tyres in the wintertime. In addition to sanding, the abrasion of pavement due to studded tyres increases the street dust emissions in urban areas.



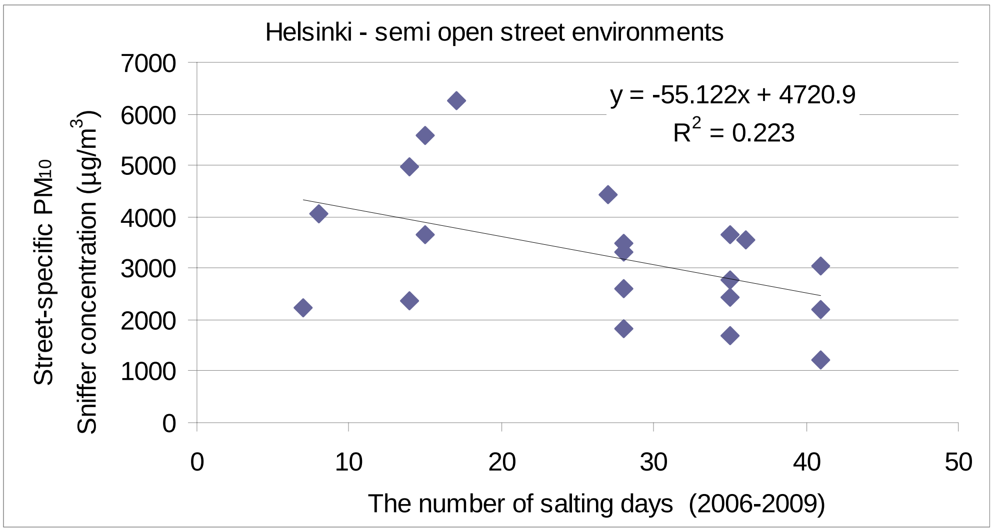


Figure 27. The number of salting days in the KAPU route in relation to springtime maximum emissions in Helsinki (2006–2009 data): in street canyons and in semi-open street environments.

4 Summary and conclusions

Street dust emission levels in the cities in Southern Finland are usually at their highest between late March and early April (week 13–16). The years 2006 and 2010 were exceptional, since spring arrived late, which affected the occurrences of peak emissions. Differences between the cities were detected depending on the presence of construction sites and differences in winter maintenance practices. Average peak emission levels in the city-specific measurement routes varied between 4 000–25 000 µg/m^3 depending on the city. Additionally street-specific variation was high. After the peak, the emissions decreased steadily and by the beginning of May, the emissions were in general on a relatively low level (Sniffer emission below 2 000 µg/m^3). Very low, summertime levels (Sniffer emission below 1 000 µg/m^3) were reached after mid-May.

Sniffer emission levels decreased simultaneously with street cleanings, but also with the decreasing number of studded tyres in use. After the spring cleanings there are usually no or very few dust deposits left in the street environments. Dust may also be transported away by atmospheric turbulences, rain and runoffs.

The emission levels had a clear response to dust binding. Information gained from the KAPU project, together with experiences from abroad showed that by dust binding it is possible to reduce the high spring time emissions and subsequent PM_{10} concentrations due to street dust. At the moment, the appropriate use of dust binding might be the only tool to combat acute street dust episodes.

Based on a literature review, traditional street cleaning equipment (mechanical street sweepers and suction sweepers) have no immediate effect on PM_{10} emissions. Thus they are not well suited to acute dust control purposes, but they may play a role in the long-term dust mitigation. With traditional street cleaning equipment it is possible to remove coarse sand and dust from the streets, and thus minimize the formation of PM_{10}-sized dust.

PIMU equipment (scrubbers with captive hydrology) represented the new technology in street cleaning in the measurements conducted during the KAPU equipment tests. Promising results were gained in the prevention of PM_{10} emissions, although “summertime” levels were not achieved with one time cleaning only. Decreases in the emission level were detected at all emission levels, but the efficiency of the PIMU equipment was best detected when the initial emission level was high (for example Sniffer emission approximately 3 500 ug/m^3 or above). With low initial dust levels, PIMU cleaning was not observed to have a clear effect. The efficiency of the PIMU equipment is likely to be due to the efficient pressurized wash combined with the intensive suction of the formed sludge.

It is worth paying attention to the filtering of the cleaning equipment outlet air. This study compared emissions of a Dulevo equipment with an advanced filtering system to those with a standard filtering system. Significant reductions in the outlet air PM_{10} concentrations were achieved with the advanced system and it was expected to mitigate the negative impact on air quality during cleaning activities.

Construction sites affect the dust emissions in nearby streets and neighborhoods. This was evident especially during summertime, when street dust emissions from other sources are low. A lot of proof data has been collected from several cities. Dust emissions from construction sites depend on the type of constructing, how much dust is spread around by construction traffic and what kind of cleaning measures are required to be performed in the construction site.

Snow collected from the side of a street side may have 15–20-fold concentrations of solid material compared to the concentrations of pristine snow. Thus it can be assumed that by transporting the snow away from the street environment it would be possible to mitigate the street dust problem. The amount of dust deposited in urban snow and ice is not known, especially not the respirable-sized particles.

The comparison between the number of sanding/salting days and emission levels indicates that the higher the amount of sanding used, the higher the peak emissions at the beginning of the spring. And on the contrary, with an increasing amount of salting, lower emissions were detected, since depending on the winter conditions these two methods are alternative traction control tools in the studied cities. This data supports the conclusion that sanding has an increasing effect on street dust emission levels, and by substituting sanding, it is possible to decrease the amount of dust. In this context, it is also worth noting, that in Finland the utilization degree of studded tyres is very high. Approximately 90% of all passenger cars use studded tyres in wintertime. In addition to sanding, the abrasion of the pavement due to studded tyres increases the street dust emissions in urban areas.

Other winter maintenance measures such as ploughing and sanding of the footpaths may have an effect on street-specific emissions but their influence was not under the scope of this study. Winter conditions also vary between different years. This may affect for example the amount of snowfall and deposits, and thus the amount of dust deposited in the vicinity of the streets.

5 Yhteenveto ja johtopäätökset

Etelä-Suomen kaupunkien katupölypäästöt ovat yleensä korkeimmillaan maaliskuun lopun ja huhtikuun alun välillä (viikot 13–16). Vuodet 2006 ja 2010 olivat poikkeuksellisia, sillä myöhäinen kevät aiheutti ajoittaisia päästöhuippuja. Päästötasot erosivat kaupunkien välillä riippuen rakennustyömaiden määrästä sekä eroista talvikunnossapidon käytännöissä. Keskimääräiset päästöhuiput vaihtelivat kaupunkikohtaisissa mittauksissa välillä 4 000–25 000 µg/m^3 kaupungista riippuen. Myös katujen välillä havaittiin merkittävää vaihtelua. Huippukauden jälkeen päästötasot alenivat tasaisesti, ja toukokuun alkuun mennessä päästöt olivat yleensä verrattain matalalla tasolla (Nuuskijan mittaamat päästöt alle 2 000 µg/m^3). Erittäin alhaiset kesätasot (Nuuskija-päästöt alle 1 000 µg/m^3) saavutettiin toukokuun puolivälin jälkeen.

Nuuskijan mittaamat päästötasot laskivat katujen puhdistuksen myötä, mutta myös liikenteessä olevien nastarenkaiden vähentyessä. Kevätpesujen jälkeen ei katuympäristössä yleensä ole enää merkittävästi hiekka- tai pölyjäämiä. Pöly voi lisäksi kulkeutua pois tuulen, sateen ja valumaveden mukana.

Pölynsidonnalla havaittiin olevan selvä vaikutus päästötasoihin. KAPU-projektissa kerätyt tiedot sekä ulkomailla saadut kokemukset osoittavat, että pölynsidonnalla voidaan alentaa kevään korkeita päästötasoja ja niistä seuraavia kohonneita hengitettävien hiukkasten (PM_{10}) pitoisuuksia. Tällä hetkellä pölynsidonta saattaa olla ainoa keino alentaa korkeita päästötasoja lyhyellä aikavälillä.

Kirjallisuusselvityksen perusteella perinteiset kadunpuhdistuslaitteet (mekaaniset lakaisukoneet ja imukoneet) eivät vaikuta PM_{10}-päästöihin välittömästi. Näin ollen ne eivät sovellu äkillisten päästöhuippujen lievittämiseen. Pitkällä aikavälillä niistä voi kuitenkin olla hyötyä pölyongelman hallinnassa. Perinteisillä laitteilla voidaan poistaa karkeaa hiekkaa ja pölyä kaduilta sekä minimoida PM_{10}-kokoisen pölyn muodostuminen.

KAPU-laitetesteissä uuden puhdistusteknologian edustajina toimivat nk. PIMU-laitteet (pesevällä imusuulakkeella varustetut katupesurit, joilla painepesun avulla poistetaan irtoaines ja pöly päällysteen raoista ja pesun seurauksena muodostuva liete imetään välittömästi pois kadun pinnalta). PM_{10}-hiukkaspäästöjen torjunnassa saatiin lupaavia tuloksia, vaikka kesäaikaisiin tasoihin ei yhdellä puhdistuskerralla päästykään. Kaikissa päästötasoissa havaittiin alenemista, mutta PIMU-laitteiden teho oli paras, kun päästöjen lähtötaso oli korkea (Nuuskija-päästötaso esim. noin 3 500 ug/m^3 tai korkeampi). Alhaisilla päästötasoilla PIMU-puhdistuksella ei huomattu olevan selvää vaikutusta. PIMU-laitteiston teho perustunee tehokkaan painepesumekanismin ja imun yhdistämiseen, jolla muodostunut liete kerätään talteen.

Puhdistuslaitteistojen poistoilman suodatukseen on syytä kiinnittää huomiota. Tässä tutkimuksessa verrattiin päästötasoja kehittyneellä suodatusjärjestelmällä varustetun Dulevo-laitteiston ja tavallisella suodatusmekanismilla varustetun laitteiston välillä. Kehittyneemmällä suodatusjärjestelmällä poistoilman PM_{10}-päästötasoja saatiin vähennettyä merkittävästi, ja järjestelmän arvioitiin lieventävän puhdistustoimien aikana aiheutuvaa ilmanlaadun huonontumista.

Rakennustyömaat vaikuttavat niiden läheisten katujen ja lähiympäristön pölytasoihin. Tämä oli ilmeistä etenkin kesällä, jolloin pölypäästöt muista lähteistä ovat vähäisiä. Havaintoa tukevia tietoja on kerätty useista kaupungeista. Rakennustyömaiden pölypäästöt riippuvat siitä, mitä työmaalla tehdään, kuinka paljon liikennettä siellä kulkee ja millaisia pölyntorjuntatoimia työmaalla vaaditaan toteutettavaksi.

Kadun varrelta kerätyssä lumessa voi olla 15–20-kertainen määrä kiintoaineita puhtaaseen lumeen verrattuna. Näin ollen voidaan olettaa, että kuljettamalla lumi pois kaduilta ja niiden läheisyydestä voidaan vähentää katupölyn vapautumista ilmaan lumien sulaessa. Kaupunkiympäristön lumeen ja jäähän sitoutuneen pölyn määristä ei ole tarkkaa tietoa, etenkään hengitettävän kokoluokan hiukkasista.

Hiekoitus-/suolauspäivien ja päästötasojen välillä tehdyt vertailut osoittavat, että suuremmat hiekoitusmäärät aiheuttavat korkeampia päästöhuippuja kevään alkuvaiheessa. Jos taas suolausta lisätään, päästötasot alenevat, sillä talven sääolosuhteista riippuen hiekoitusta ja suolausta käytetään toisiaan korvaavina liukkaudenpoistomenetelminä. Nämä tiedot tukevat päätelmää, että hiekoituksella on vaikutusta katujen pölypäästötasoihin ja että hiekoitusta vähentämällä voidaan vaikuttaa pölyn määrään. Tässä yhteydessä on myös syytä huomioida, että Suomessa nastarenkaat ovat yleisiä. Niitä käytetään talvisin noin 90 prosentissa henkilöautoista. Hiekoituksen lisäksi myös nastojen tien pintaan kohdistama kulutus lisää pölyn määrää kaupunkialueilla.

Muut talvikunnossapitoon liittyvät toimet, kuten auraus ja jalkakäytävien hiekoitus, voivat vaikuttaa katukohtaisiin päästötasoihin, mutta niitä ei tarkasteltu tämän tutkimuksen puitteissa. Talviolosuhteet voivat myös vaihdella eri vuosina, millä saattaa olla vaikutusta esim. lumen määrään ja kertymiin, ja näin ollen katuympäristöön kerääntyvän hiekan ja pölyn määrään.

6 Sammanfattning och slutledningar

Utsläppsnivåerna av gatudamm i städer i södra Finland brukar ligga som högst mellan slutet av mars och början av april (vecka 13–16). Åren 2006 och 2010 var exceptionella eftersom våren anlände sent, vilket påverkade förekomsten av utsläppstoppar. Skillnader mellan städer upptäcktes beroende på förekomsten av byggarbetsplatser och skillnader i rutiner för vinterunderhåll. Genomsnittsnivåer på utsläppstoppar i de stadsspecifika mätrutterna varierade mellan 4 000-25 000 µg/m^3 beroende på stad. Variationerna för specifika gator var dessutom höga. Efter toppen minskade utsläppen stadigt och i början av maj låg utsläppen i allmänhet på en relativt låg nivå (mätningar med Nuuskija-bilen gav utsläpp under 2 000 µg/m^3). Mycket låga sommarnivåer (Nuuskija-utsläpp under 1 000 µg/m^3) uppnåddes efter mitten av maj.

Nuuskija-utsläppsnivåer sjönk samtidigt med gatustädningen, men även med det minskande antalet dubbdäck som var i bruk. Efter vårrengöringen finns det vanligen inga eller mycket få dammavlagringar kvar i gatumiljöerna. Damm kan även föras bort av atmosfärisk turbulens, regn och avrinning.

Utsläppsnivåerna svarade tydligt på dammbindning. Information som samlades in från KAPU-projektet, tillsammans med erfarenheter från utlandet, visade att det genom dammbindning är möjligt att minska höga vårutsläpp och därav följande höga koncentrationer av inandningsbara partiklar (PM_{10}). För närvarande kan lämplig användning av dammbindning vara det enda verktyget för att bekämpa akuta episoder med gatudamm.

Grundat på en genomgång av litteraturen har traditionell gatustädningsutrustning (mekaniska gatsopare och sugsopare) ingen omedelbar inverkan på PM_{10}-utsläpp. De är således inte lämpade för akuta dammkontrollsändamål, men de kan spela en roll i den långsiktiga minskningen av damm. Med traditionell gatustädningsutrustning är det möjligt att avlägsna grov sand och grovt damm från gatorna och därmed minimera bildandet av damm i PM_{10}-storlek.

PIMU-utrustning (våtrenare med inkapslad hydrologi) representerade den nya gatustädningstekniken i de mätningar som utfördes under KAPU:s utrustningstester. Lovande resultat uppnåddes i förebyggandet av PM_{10}-utsläpp, även om "sommarnivåer" inte uppnåddes med bara en städningsomgång. Minskningar i utsläppsnivån upptäcktes vid alla utsläppsnivåer, men PIMU-utrustningens verkningsfullhet märktes mest när den ursprungliga utsläppsnivån var hög (t.ex. Nuuskija-utsläpp cirka 3 500 ug/m^3 eller högre). Vid låga ursprungliga dammnivåer observerades inte någon tydlig verkan från PIMU-städning. PIMU-utrustningens verkningsfullhet beror troligen på den effektiva trycktvätten i kombination med den intensiva insugningen av det uppkomna slammet.

Det är värt att ägna uppmärksamhet åt filtreringen av städningsutrustningens utloppsluft. I denna studie jämfördes utsläppen från en Dulevo-utrustning med ett avancerat filtreringssystem och utrustning med ett standardfiltreringssystem. Signifikanta minskningar i PM_{10}-koncentrationer i utloppsluft uppnåddes med det avancerade systemet och det bedömdes att det lindrade den negativa inverkan på luftkvaliteten under städningsaktiviteter.

Byggplatser påverkar dammutsläpp i angränsande gator och närområden. Detta var tydligt särskilt sommartid, då gatudammutsläpp från andra källor är låga. Mycket bevisunderlag har insamlats från flera städer. Dammutsläppen från byggarbetsplatser beror på typen av byggnation, hur mycket damm som sprids omkring av byggtrafiken och vilken typ av städningsåtgärder som måste utföras på byggplatsen.

Snö som insamlats från vägkanten kan innehålla 15–20-faldiga koncentrationer av fast material jämfört med koncentrationer i nysnö. Det kan därför antas att det genom att forsla bort snön från gatumiljön vore möjligt att lindra gatudammproblemet. Mängden damm som hamnar i snö och is i stadsmiljö är inte känd, i synnerhet inte de partiklar som kan andas in.

Jämförelsen mellan antalet sandnings-/saltningsdagar och utsläppsnivåerna ger vid handen att ju större mängd sand som används, desto högre utsläppstoppar i början av våren. Och tvärtom, med ökande saltning upptäcktes lägre utsläpp, eftersom, beroende på vinterförhållandena, dessa två metoder är alternativa verktyg för halkbekämpning i de studerade städerna. Dessa uppgifter stödjer slutsatsen att sandning har en ökande inverkan på nivåerna av gatudammutsläpp och genom att byta ut sandningen är det möjligt att minska mängden damm. Det är i detta sammanhang värt att notera att användningen av dubbdäck i Finland är mycket hög. Cirka 90 % av alla personbilar använder dubbdäck under vintern. Förutom sandning ökar slitaget av gatubeläggningen på grund av dubbdäck gatudammutsläppen i stadsområden.

Andra vinterunderhållsåtgärder som t.ex. plogning och sandning av gångstigar kan ha inverkan på gatuspecifika utsläpp, men deras inverkan ingick inte i denna studies omfattning. Vinterförhållanden kan också variera från år till år. Detta kan påverka t.ex. mängden nedfallen snö och avlagringar och således mängden damm som avlagras i gatornas närhet.

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Annex 1. The map of Finland and the location of the KAPU cities

Figure 1. Map of Finland.

Figure 2. The location of KAPU cities in southern Finland. (Copyright: Maanmittauslaitos, www.maanmittauslaitos.fi.)

Population in the KAPU cities (November 2010):

Espoo 247 577
Helsinki 588 068
Kerava 34 226
Porvoo 48 805
Tampere 213 210
Turku 177 523
Vantaa 199 910

Source: Tilastokeskus - Statistics Finland, www.stat.fi.

Annex 2. Street- and route-specific average emission levels in KAPU cities (2006–2010)

Espoo (2006–2010)
Streets in the Espoo KAPU route have been divided into two groups which are presented in separate figures. Early spring and late spring concentrations are also separated in different figures (note the scale).

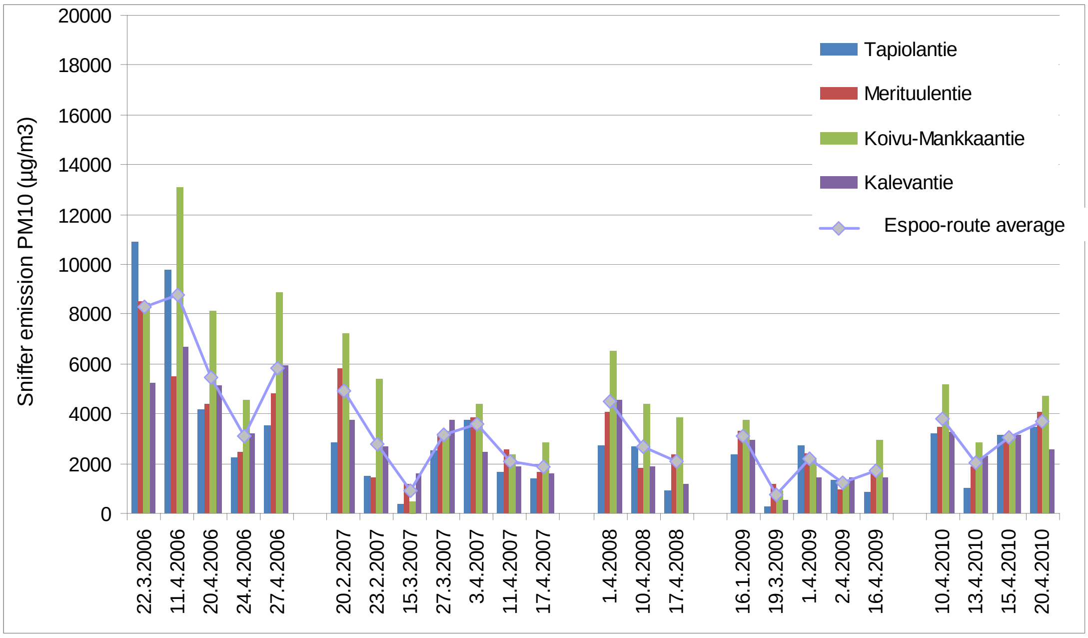


Figure 1. Espoo, group 1 streets - early spring

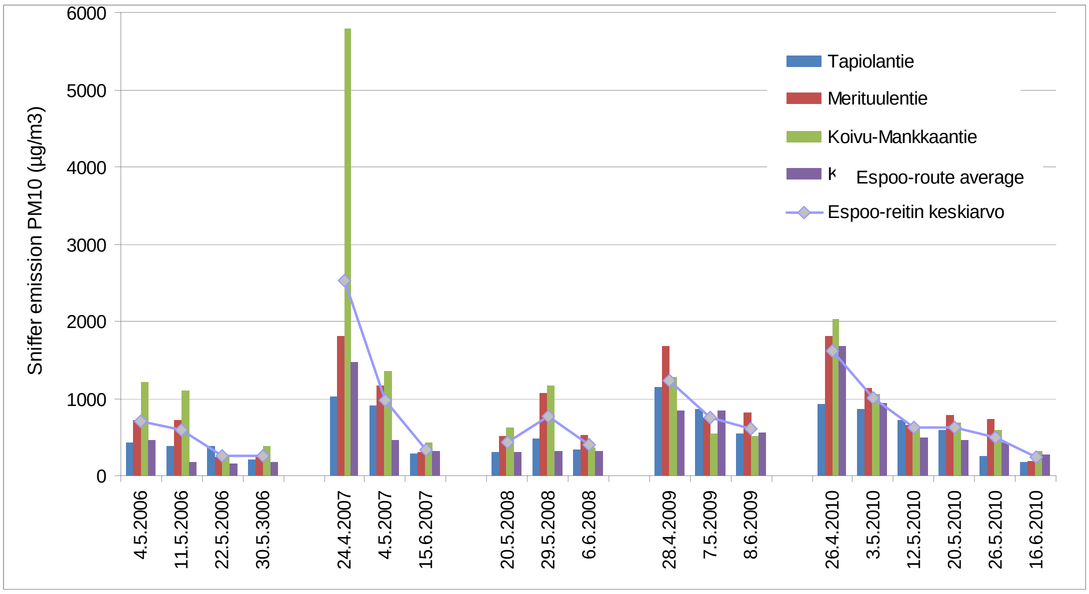


Figure 2. Espoo, group 1 streets - late spring

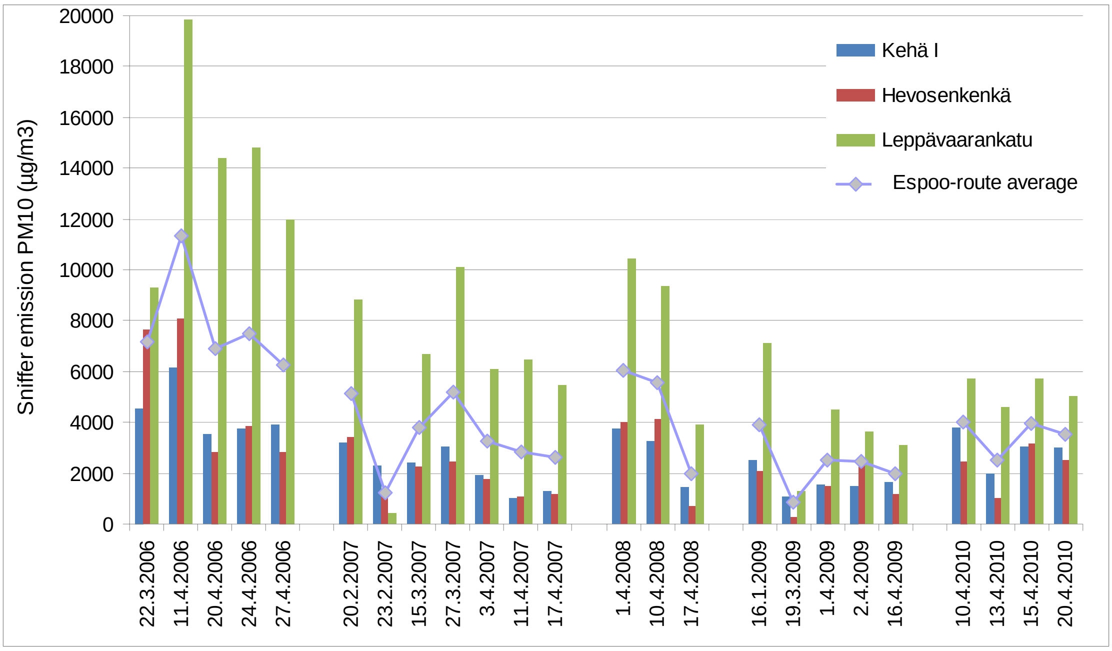


Figure 3. Espoo, group 2 streets - early spring

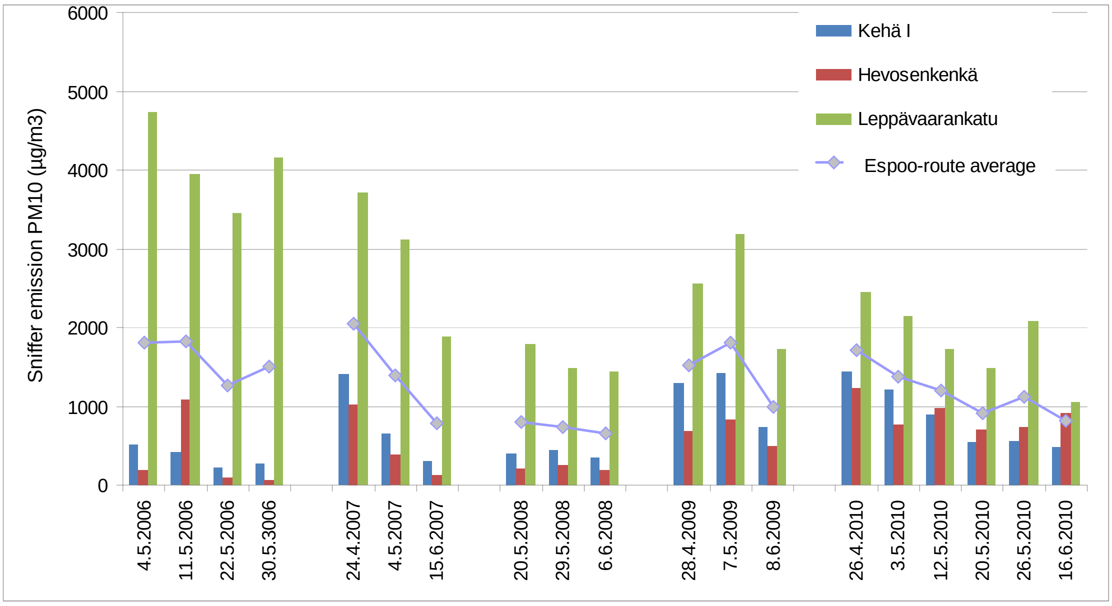


Figure 4. Espoo, group 2 streets - late spring

Helsinki (2006–2010)

Streets in the Helsinki KAPU route have been divided into three groups, that are presented in separate figures. Early spring and late spring emissions are also separated in different figures (note the scale).

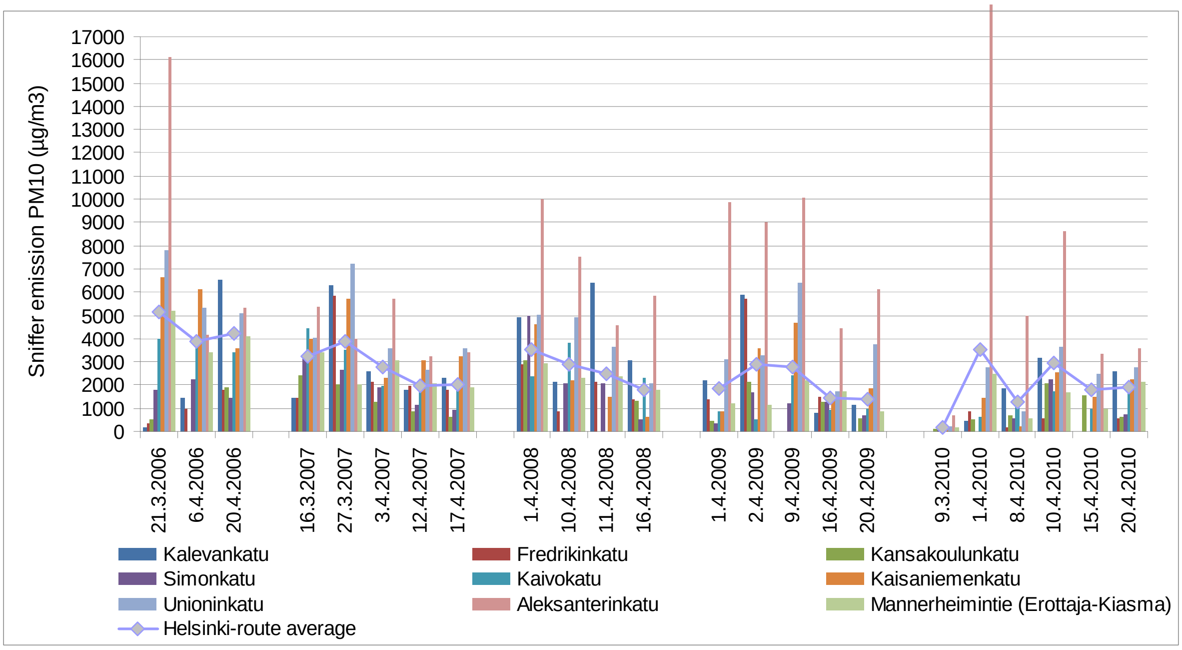


Figure 5. Helsinki, city centre - early spring

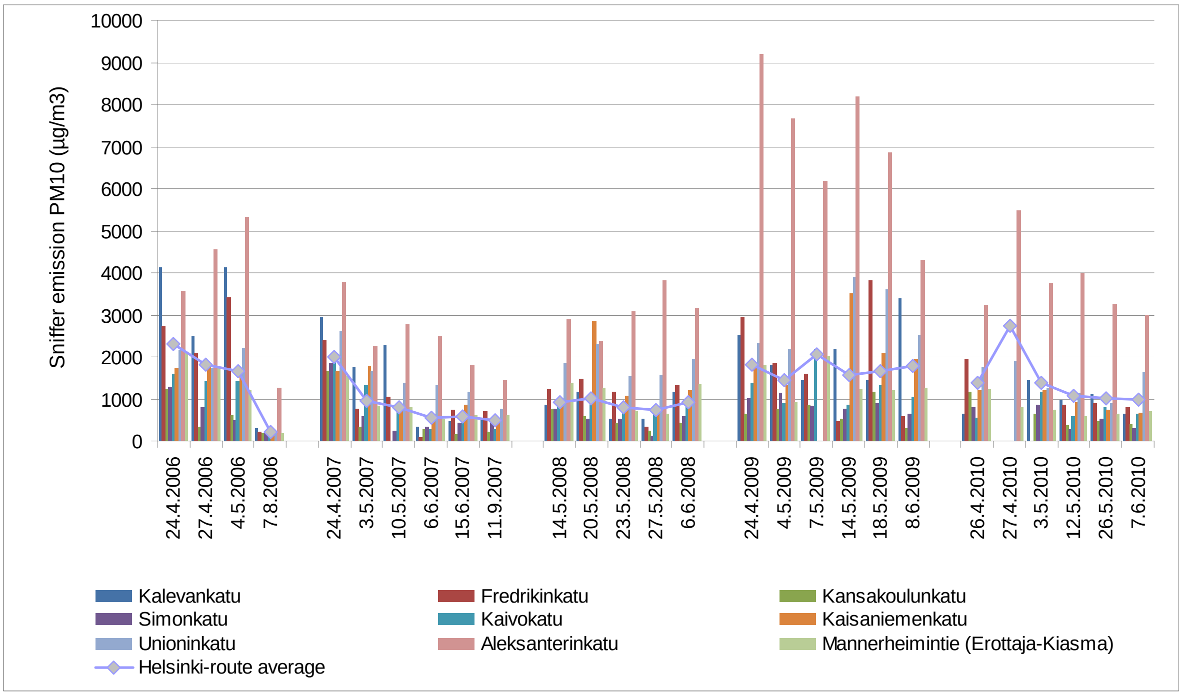


Figure 6. Helsinki, city centre - late spring

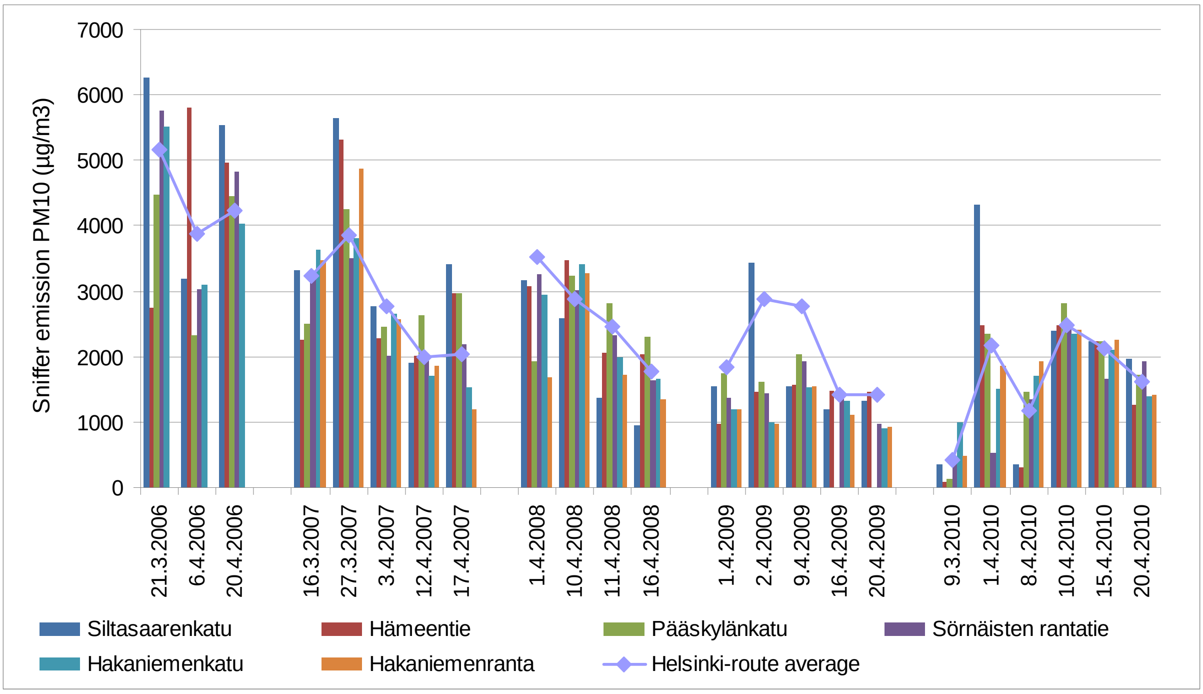


Figure 7. Helsinki East- early spring

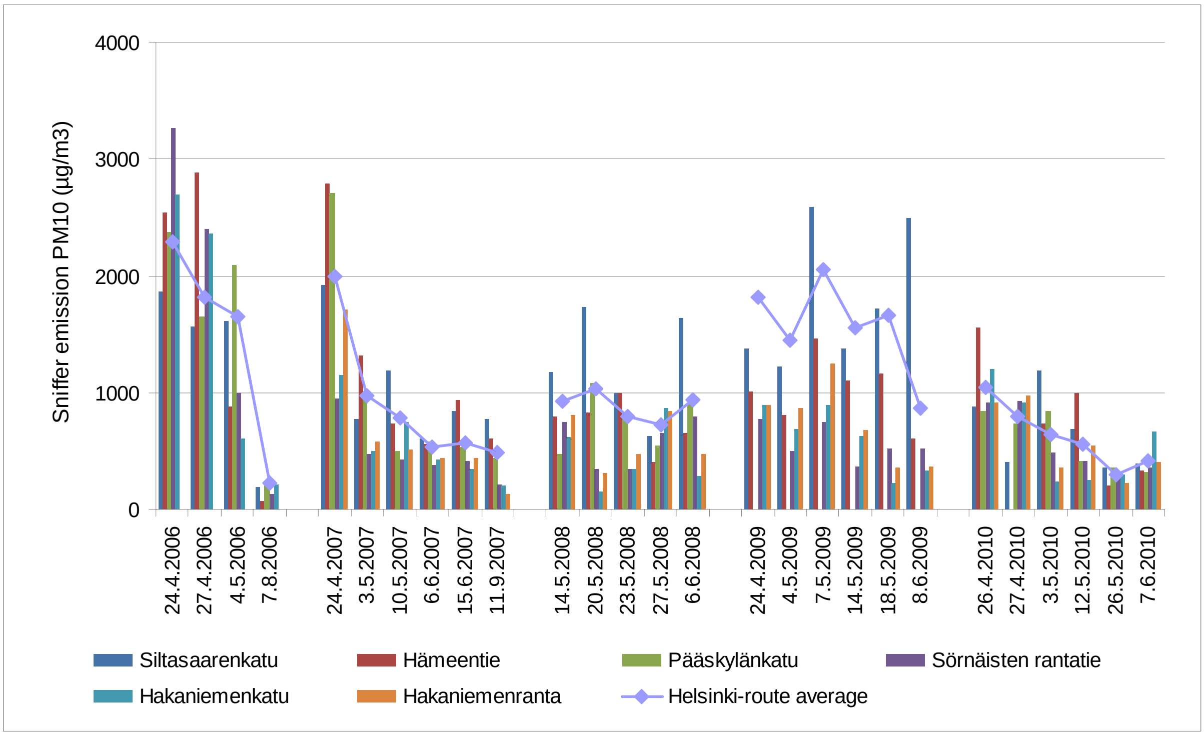


Figure 8. Helsinki East- late spring

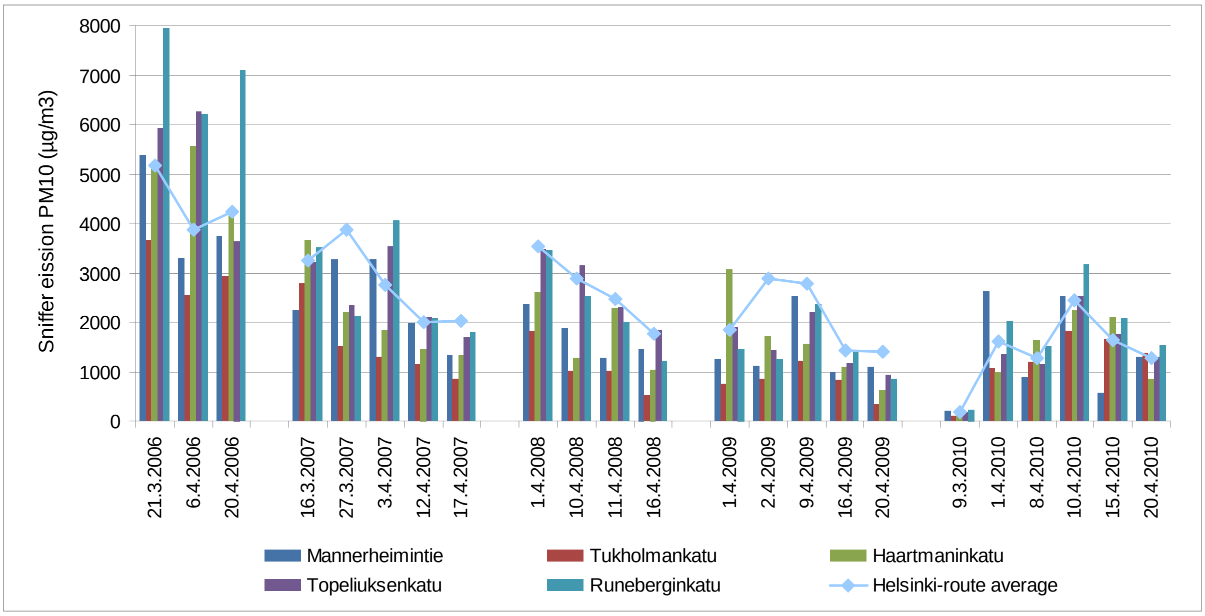


Figure 9. Helsinki Töölö (west) - early spring

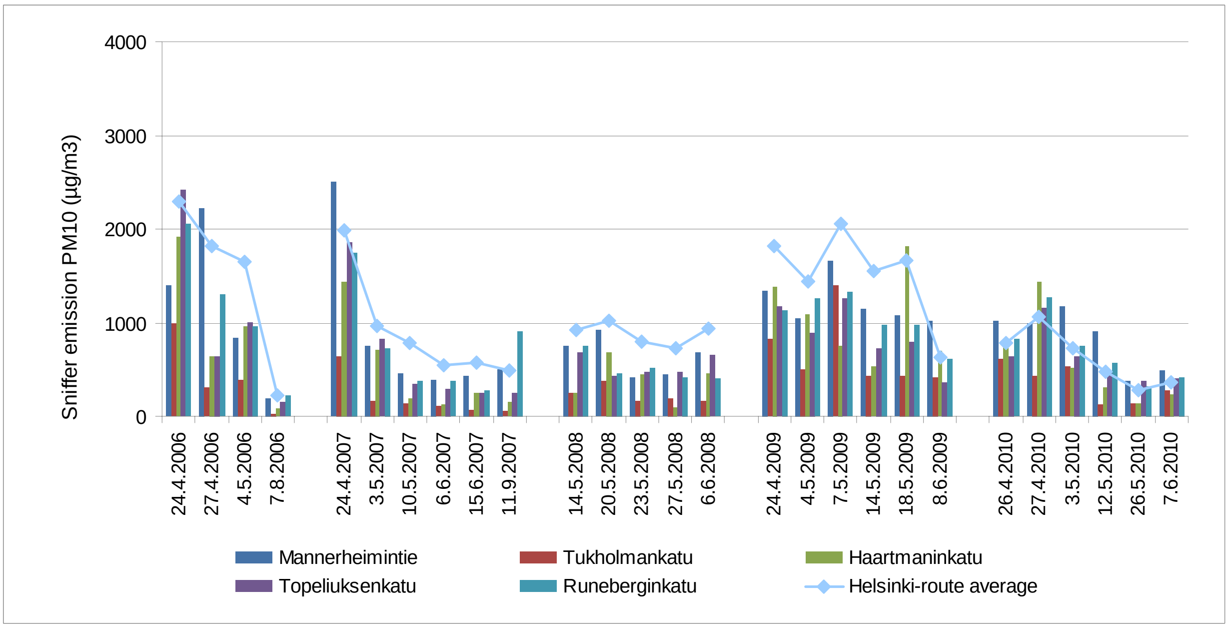


Figure 10. Helsinki Töölö (west) - late spring

Kerava (2006–2009)

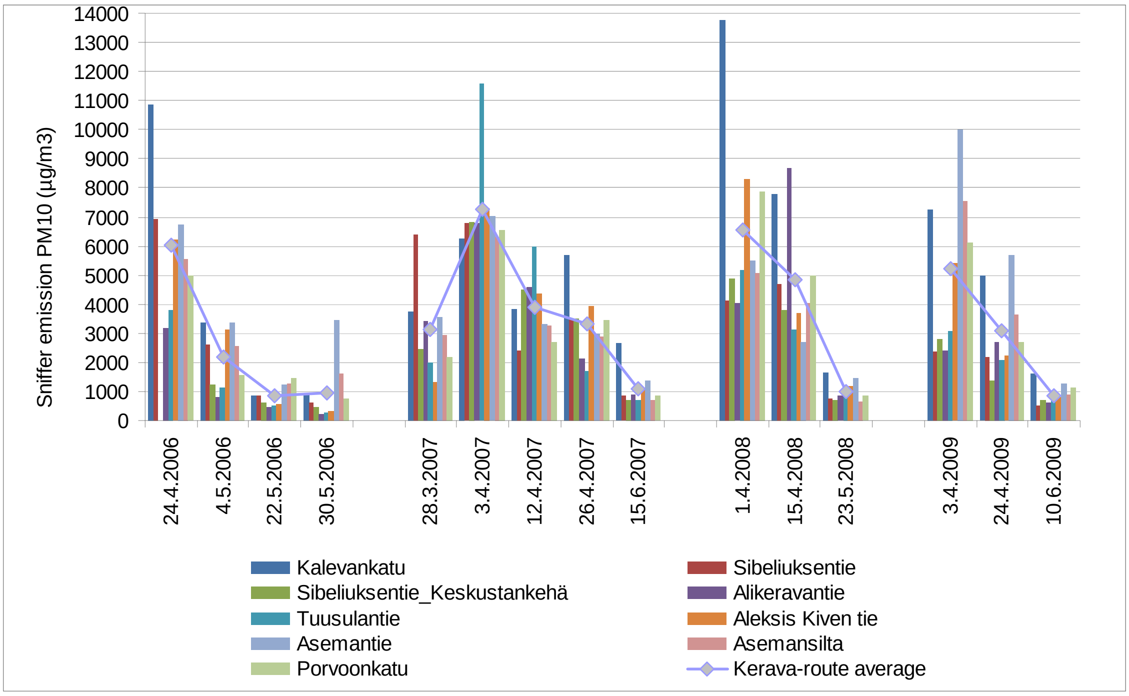


Figure 11. Kerava - whole spring

Porvoo (2010)

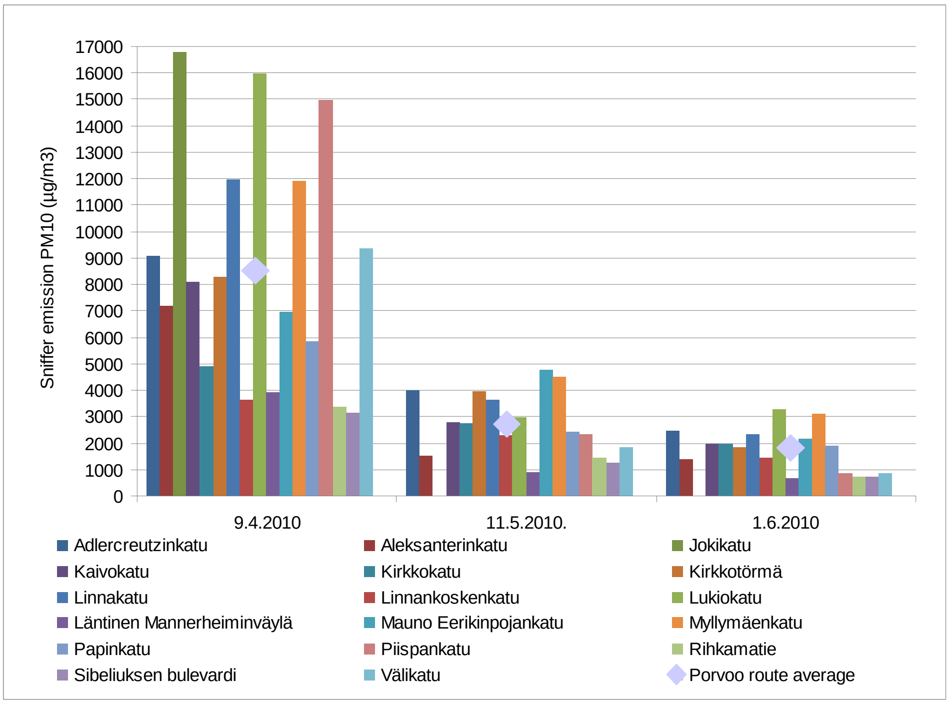


Figure 12. Porvoo - whole spring

Riihimäki (2006–2010)

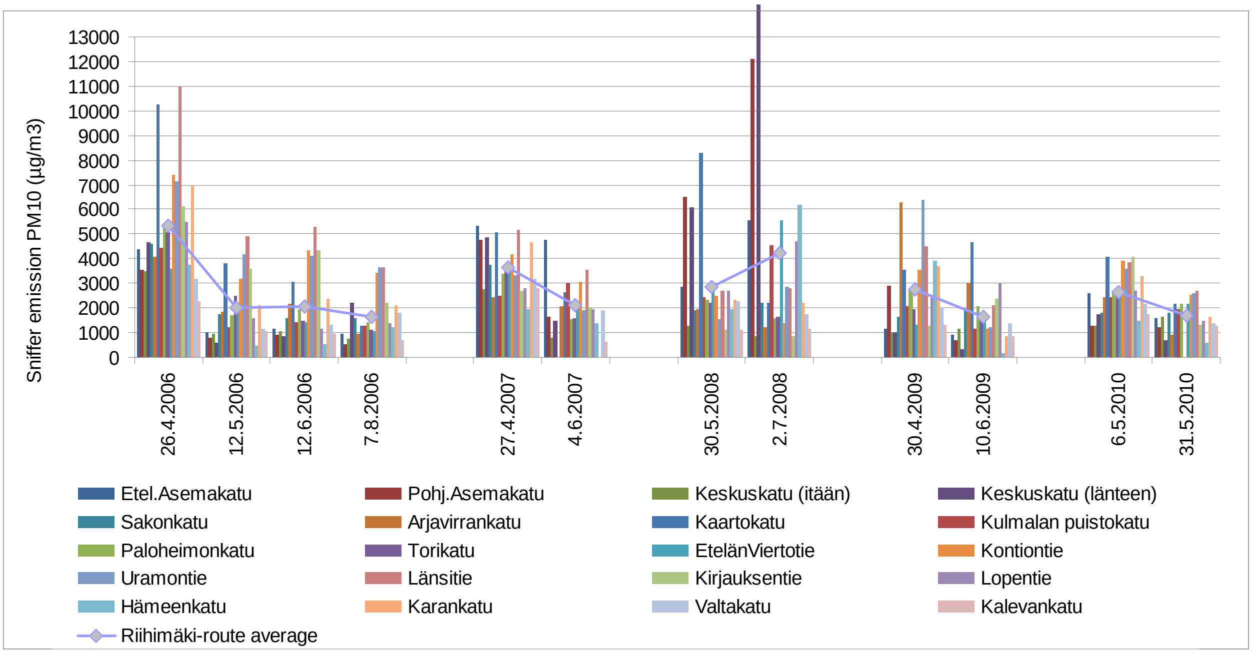


Figure 13. Riihimäki - whole spring

Tampere (2006–2010)

Streets in the Tampere KAPU route have been divided into three groups, which are presented in separate figures. Early spring and late spring emissions are also separated in different figures (note the scale).

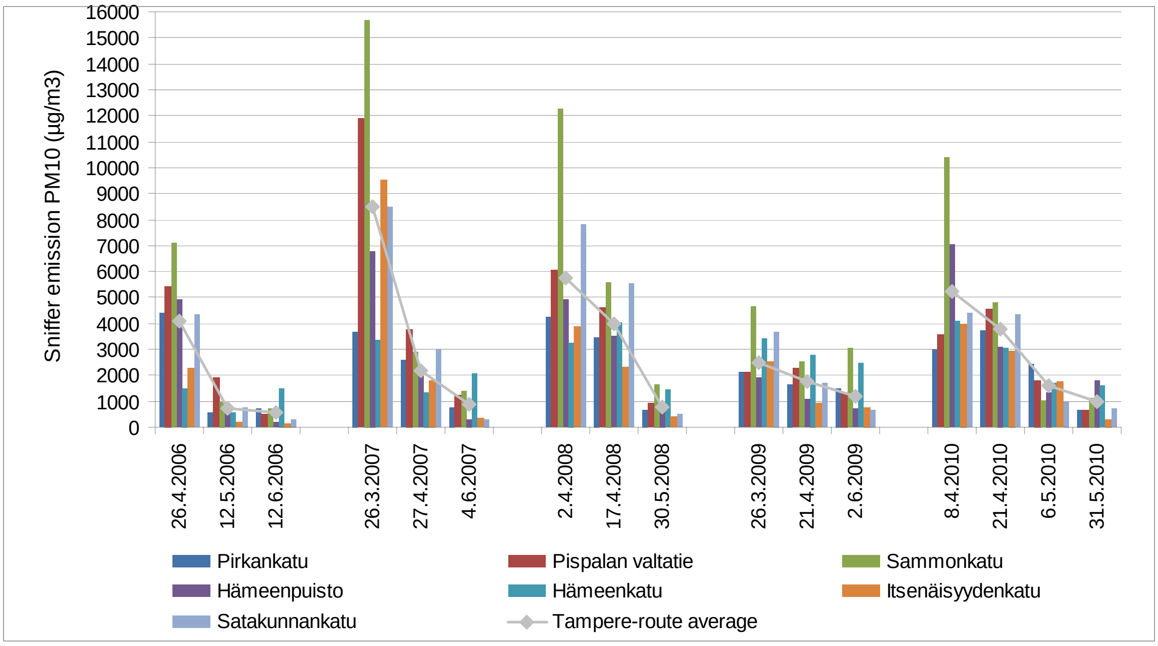


Figure 14. Tampere, group 1 streets – whole spring

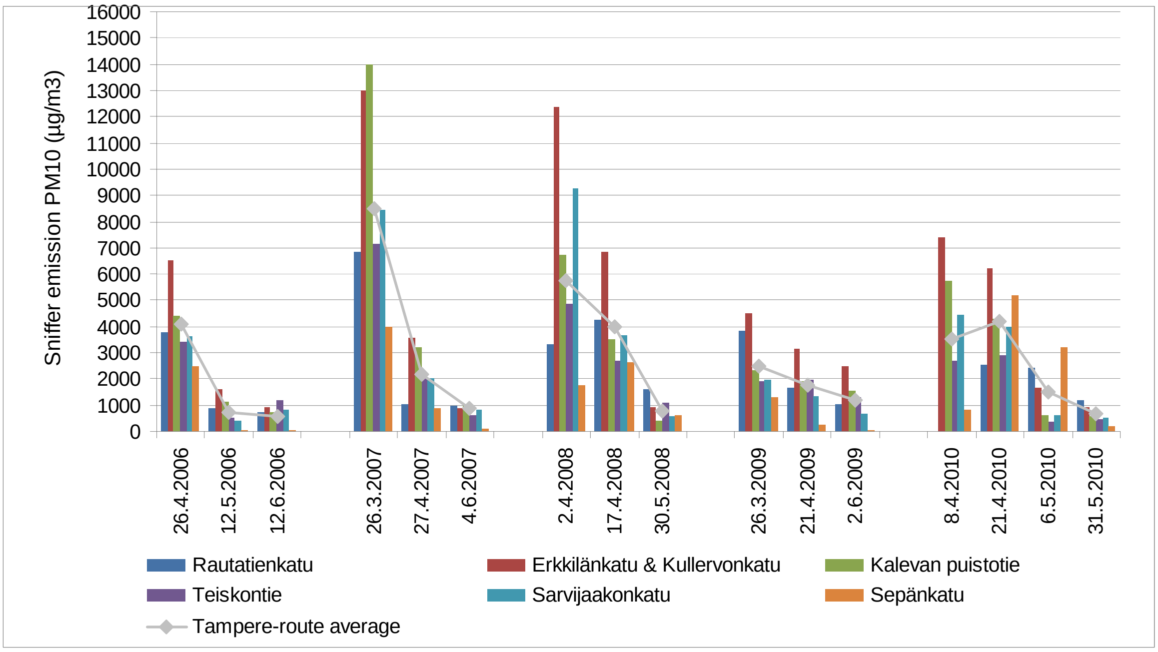


Figure 15. Tampere, group 2 streets – whole spring

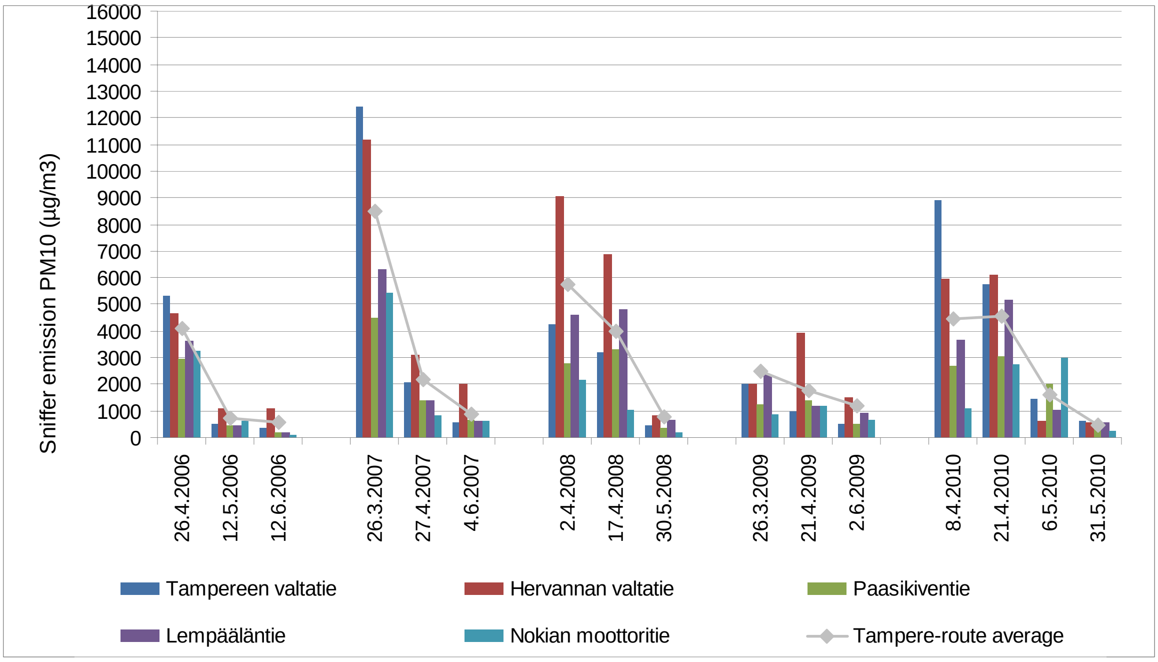


Figure 16. Tampere, group 3 streets – whole spring

Turku (2008–2009)

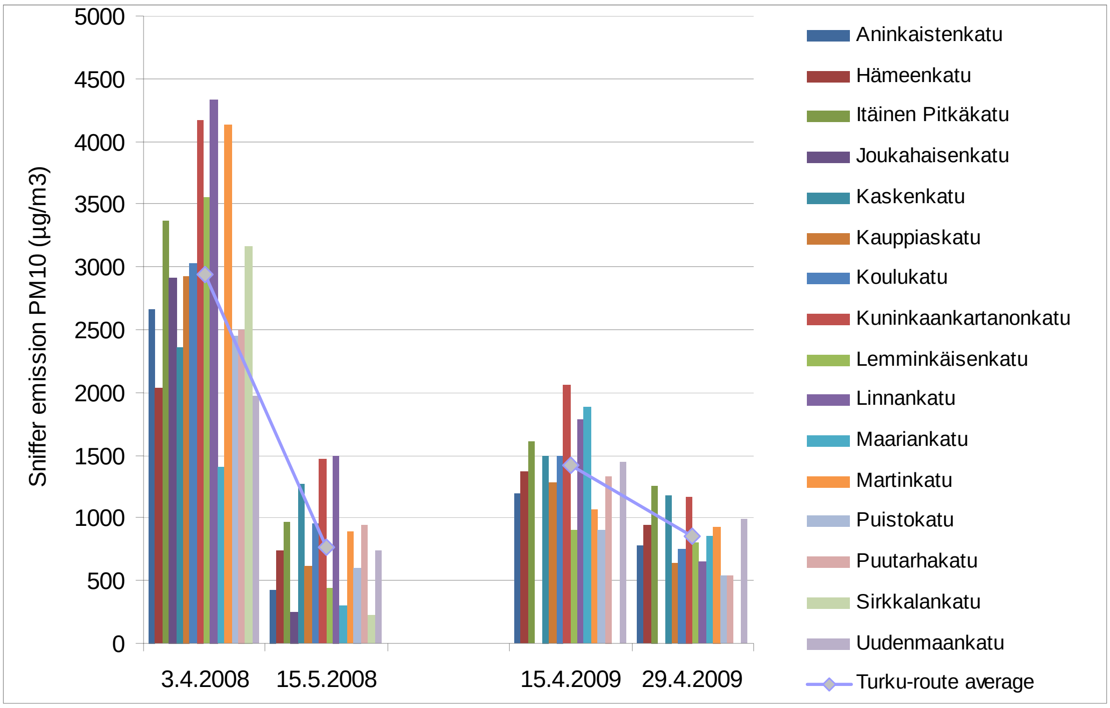


Figure 17. Turku – whole spring

Vantaa (2006–2010)

Early spring and late spring emissions are separated in different figures (note the scale).

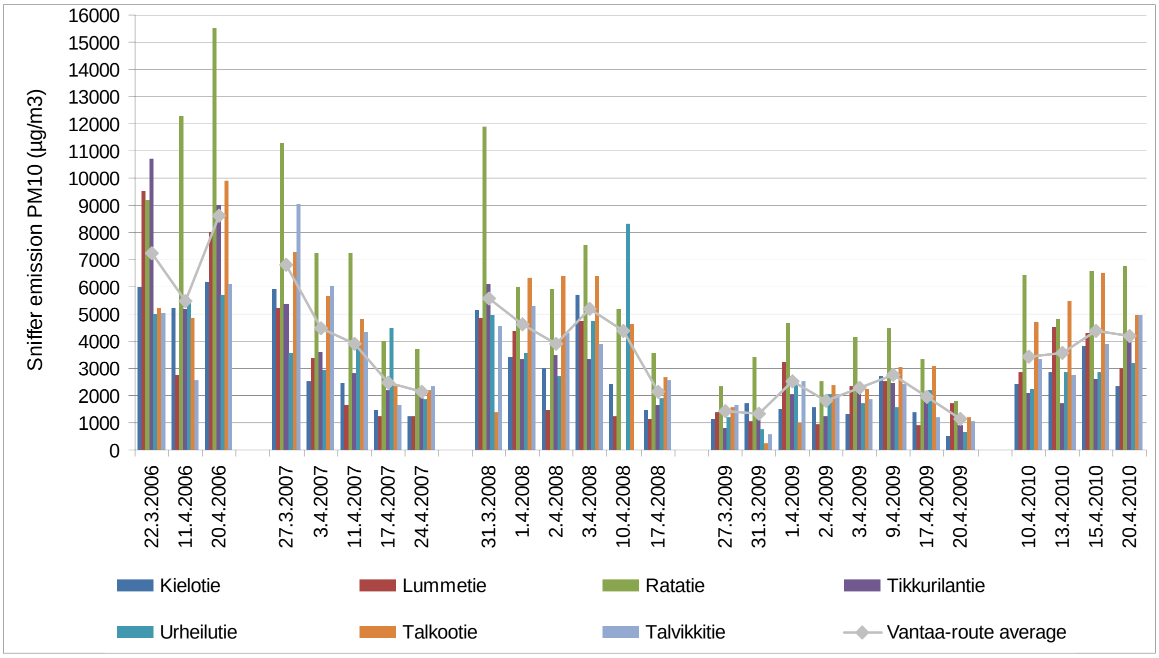


Figure 18. Vantaa – early spring

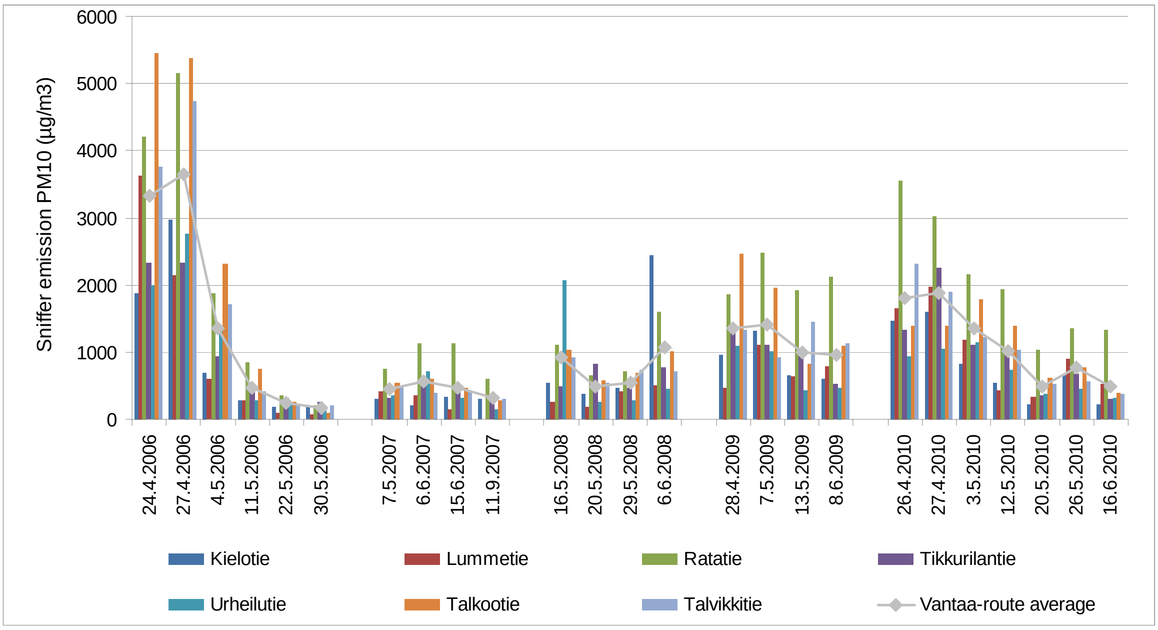
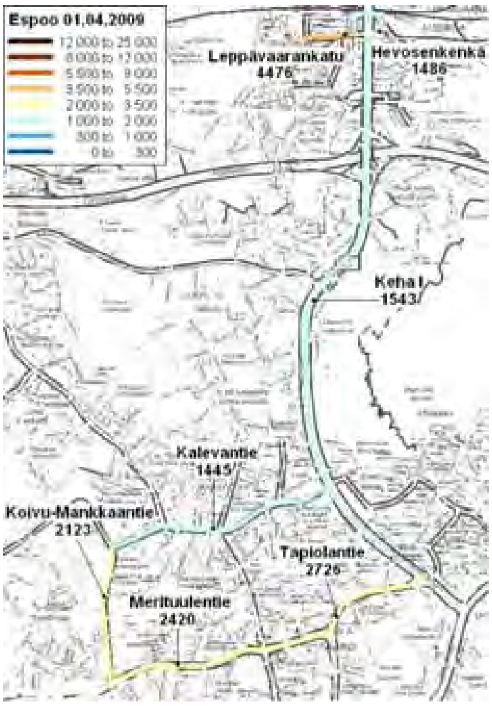


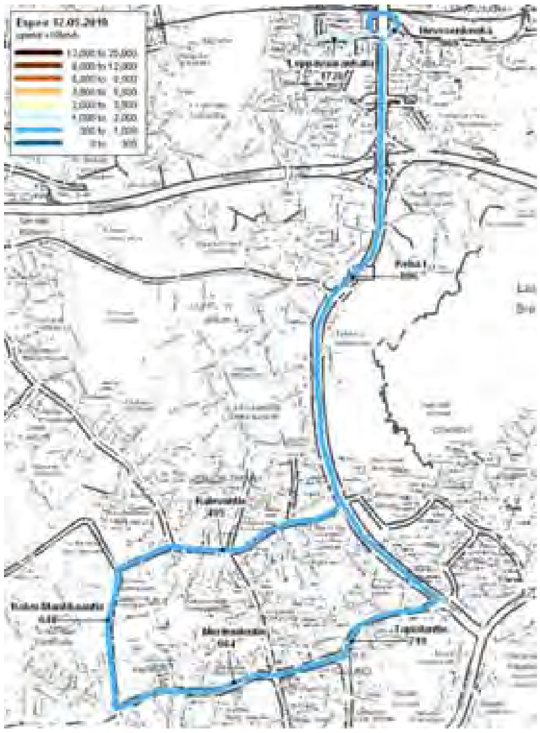
Figure 19. Vantaa – late spring

Annex 3. Street average emissions presented as maps for KAPU cities: early spring vs. late spring (2006–2010).

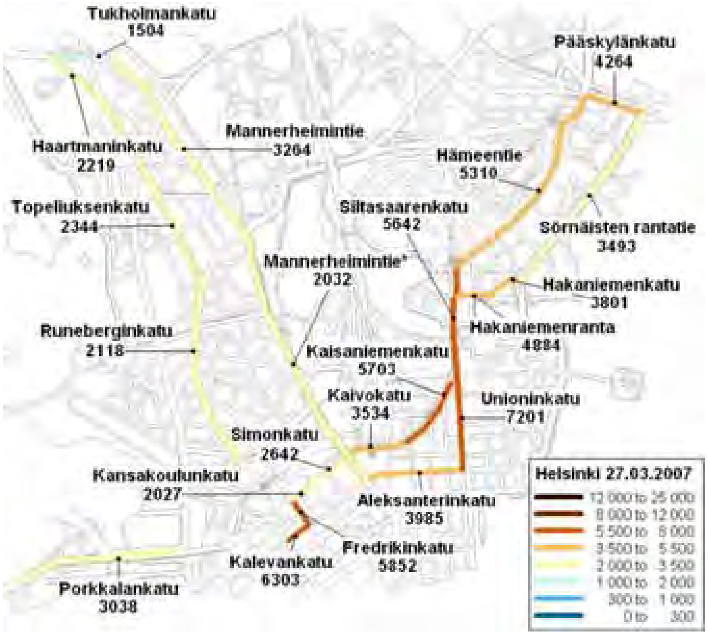
Espoo route - Early spring 2006–2010

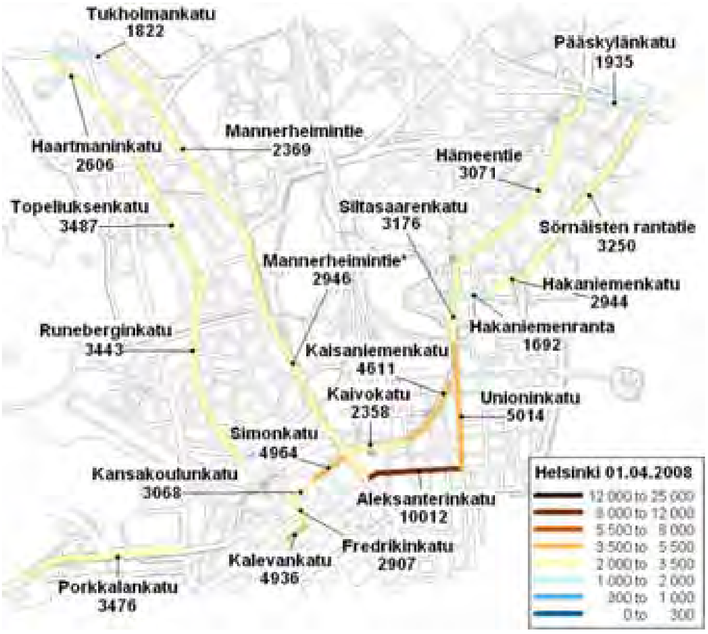


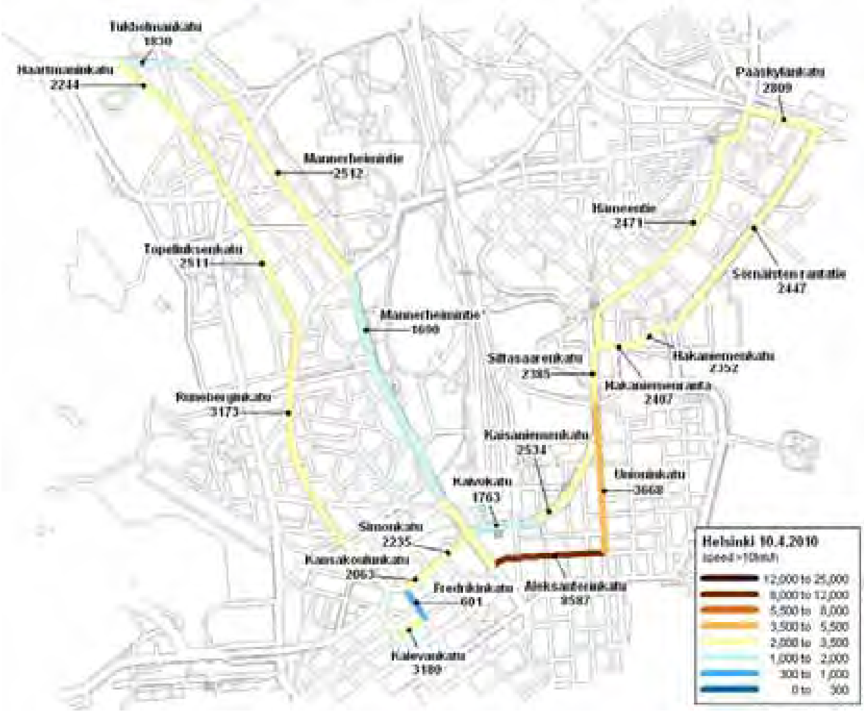
Espoo route – Late spring/early summer (after the cleaning) 2006–2010



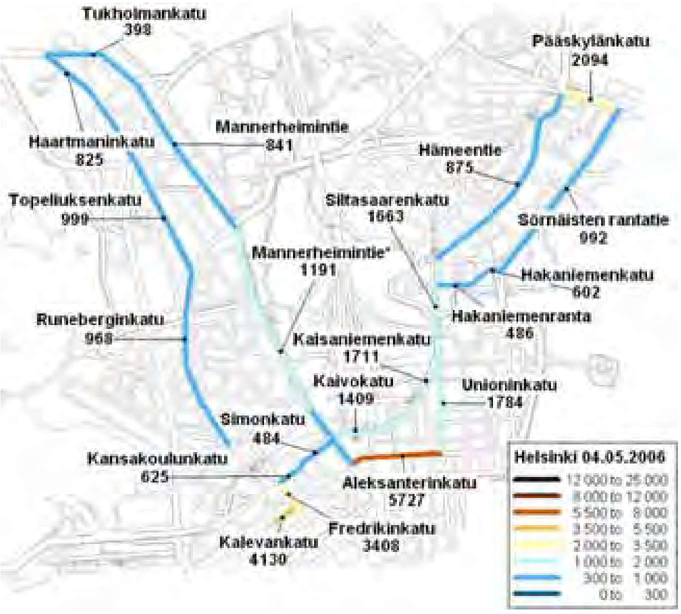
Helsinki route - Early spring 2006–2010

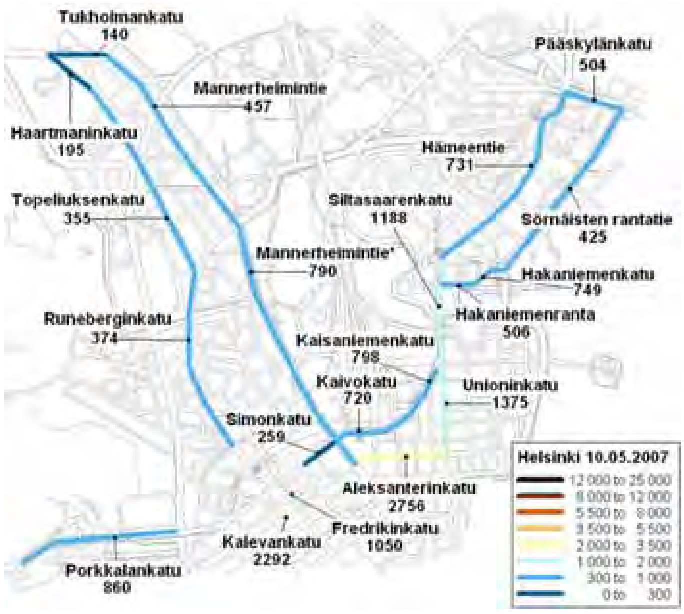


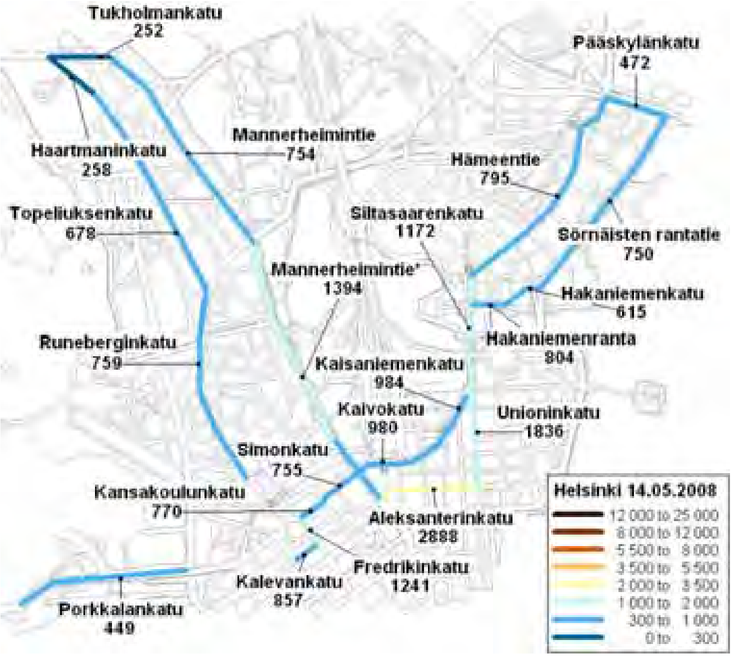




Helsinki route – Late spring/early summer (after the cleaning) 2006–2010






Tukholmankatu
252
Pääskylänkatu
472
Mannerheimintie
754
Haartmaninkatu
258
Hämeentie
795
Topeliuksenkatu
678
Siltasaarenkatu
1172
Sörnäisten rantatie
750
Mannerheimintie*
1394
Hakaniemenkatu
615
Runeberginkatu
759
Hakaniemenranta
804
Kaisaniemenkatu
984
Kaivokatu
980
Unioninkatu
1836
Simonkatu
755
Kansakoulunkatu
770
Aleksanterinkatu
2888
Fredrikinkatu
1241
Kalevankatu
857
Porkkalankatu
449
Helsinki 14.05.2008
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2 000 to 3 500
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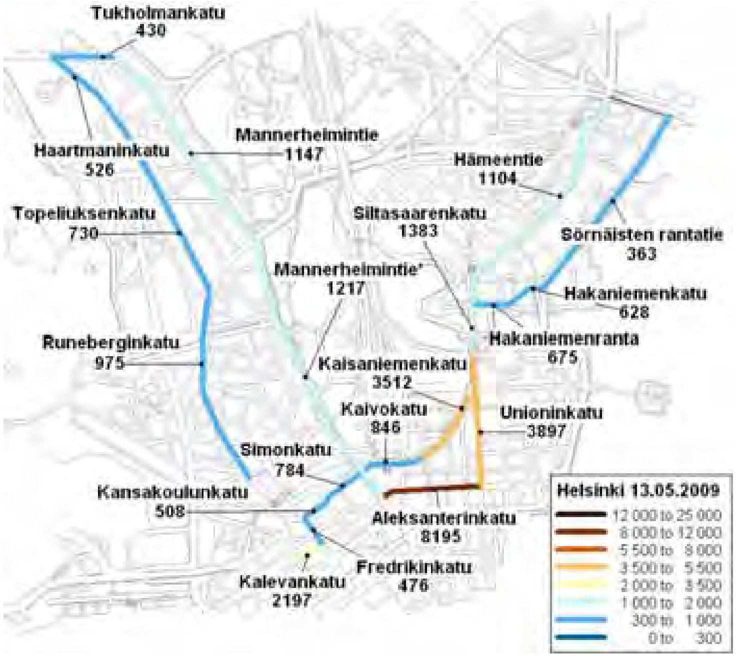
0 to 300


Tukholmankatu
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Haartmaninkatu
526
Mannerheimintie
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Hämeentie
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Topeliuksenkatu
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Siltasaarenkatu
1383
Sörnäisten rantatie
363
Mannerheimintie*
1217
Hakaniemenkatu
628
Runeberginkatu
975
Hakaniemenranta
675
Kaisaniemenkatu
3512
Kaivokatu
846
Unioninkatu
3897
Simonkatu
784
Kansakoulunkatu
508
Aleksanterinkatu
8195
Fredrikinkatu
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Kalevankatu
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Helsinki 13.05.2009
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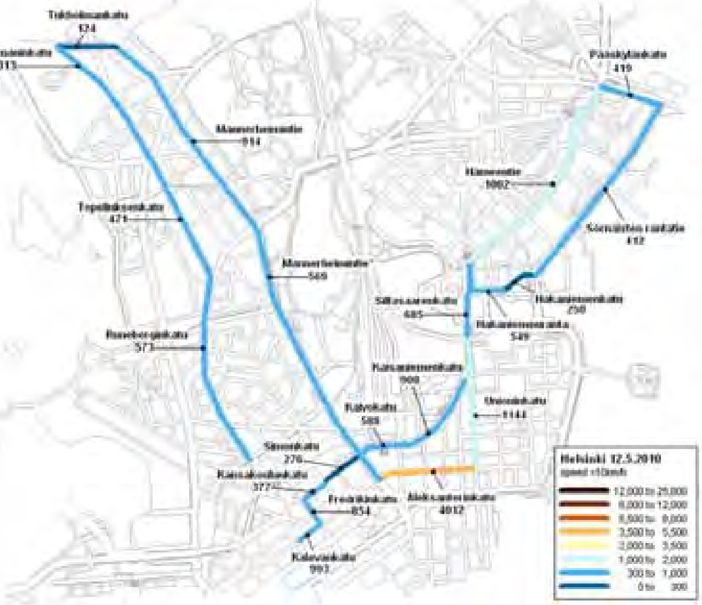
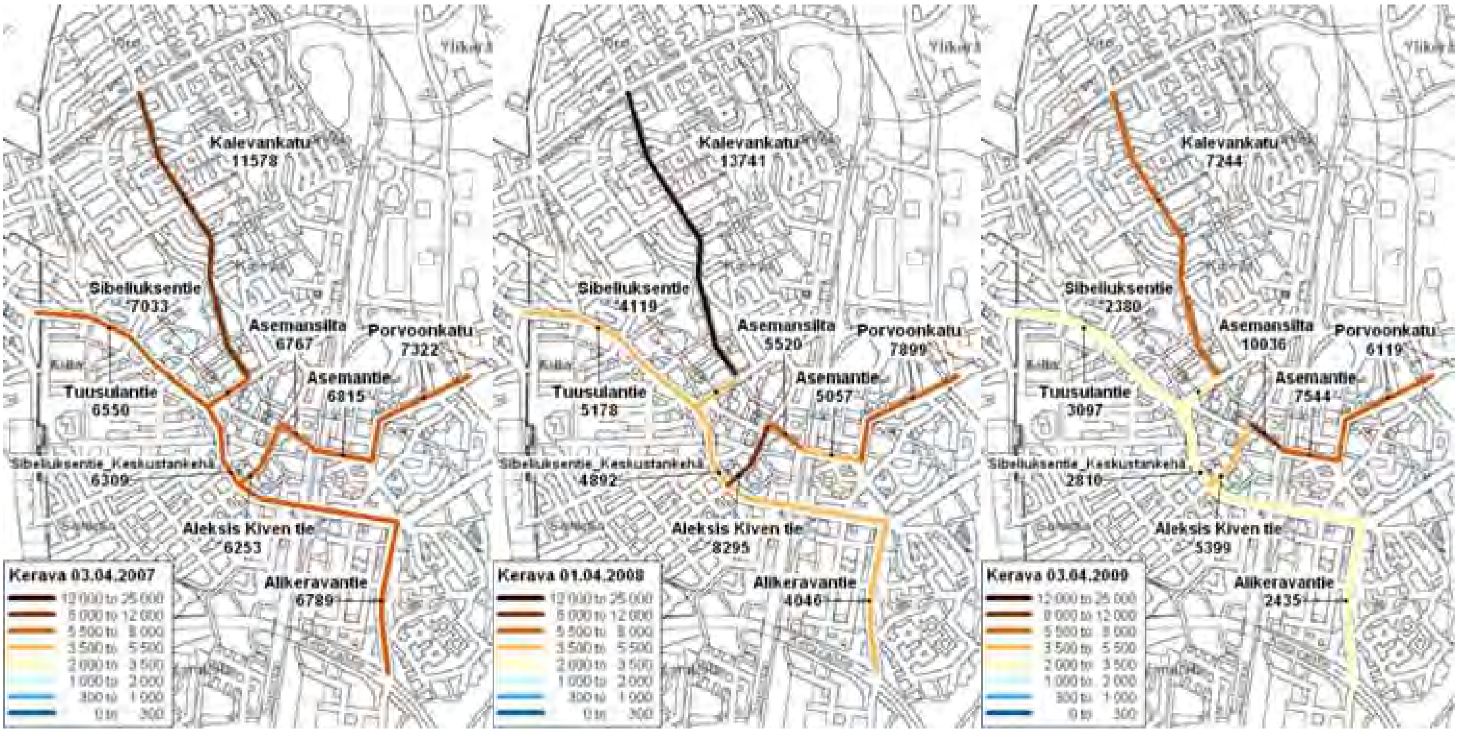
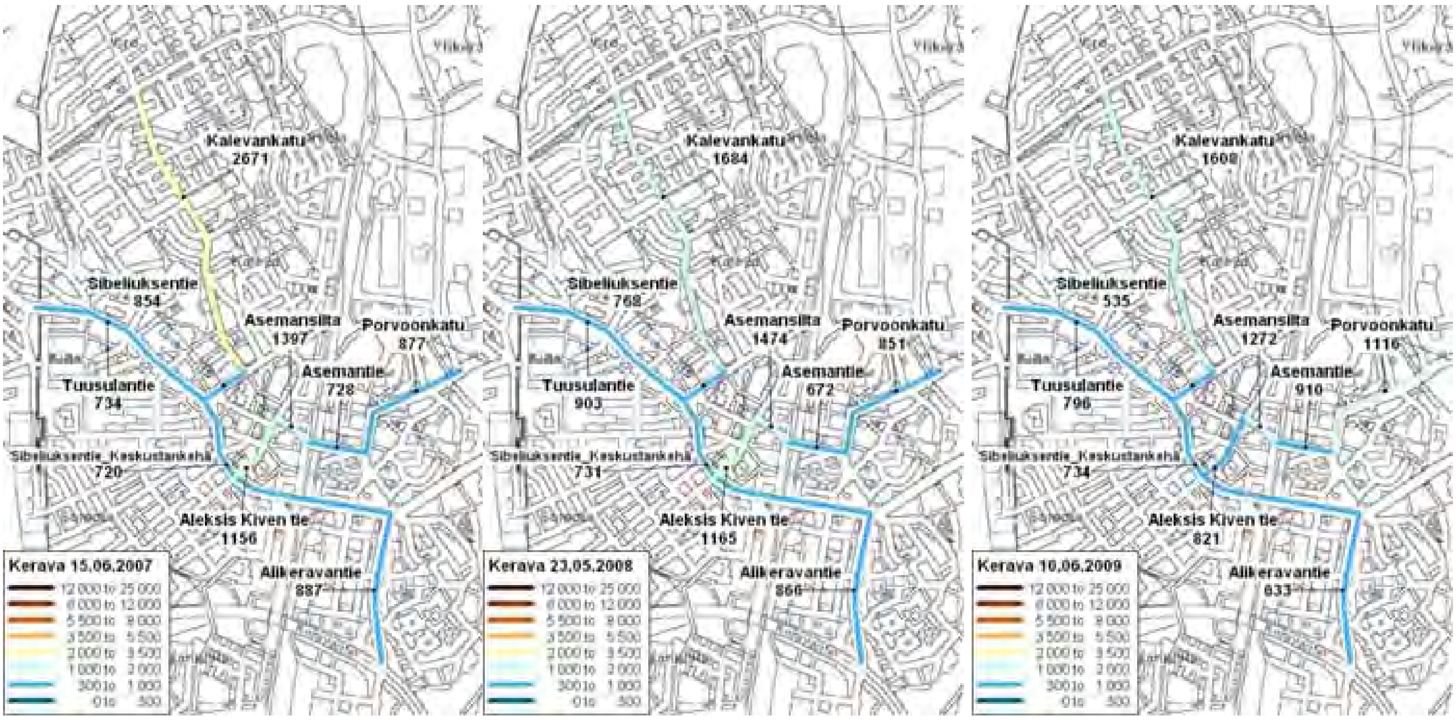

Helsinki 12.5.2010

Kerava route - Early spring (2007–2009)



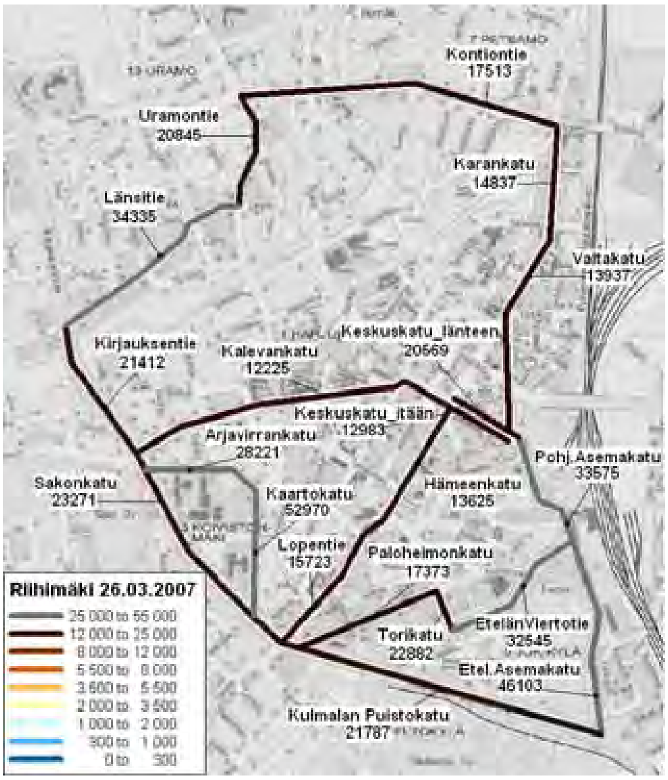
Kerava route – Late spring/early summer (after the cleaning) 2007–2009

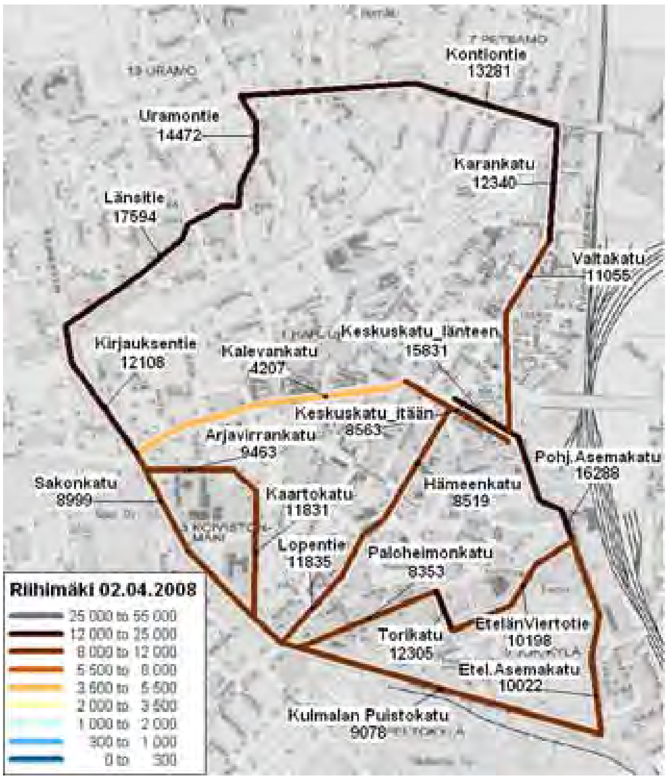


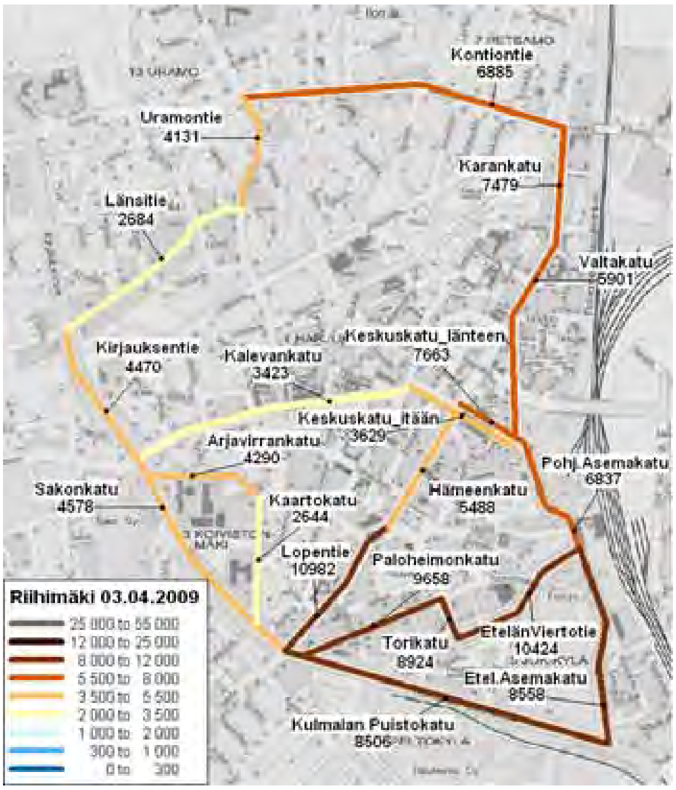
Porvoo route - Early spring 2010

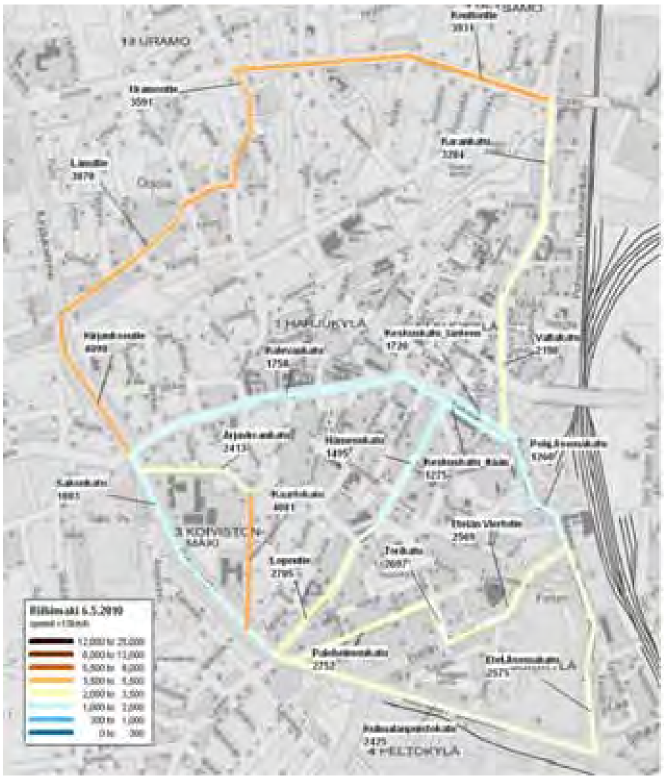
Late spring (after the cleaning) 2010

Riihimäki route - Early spring 2007–2010

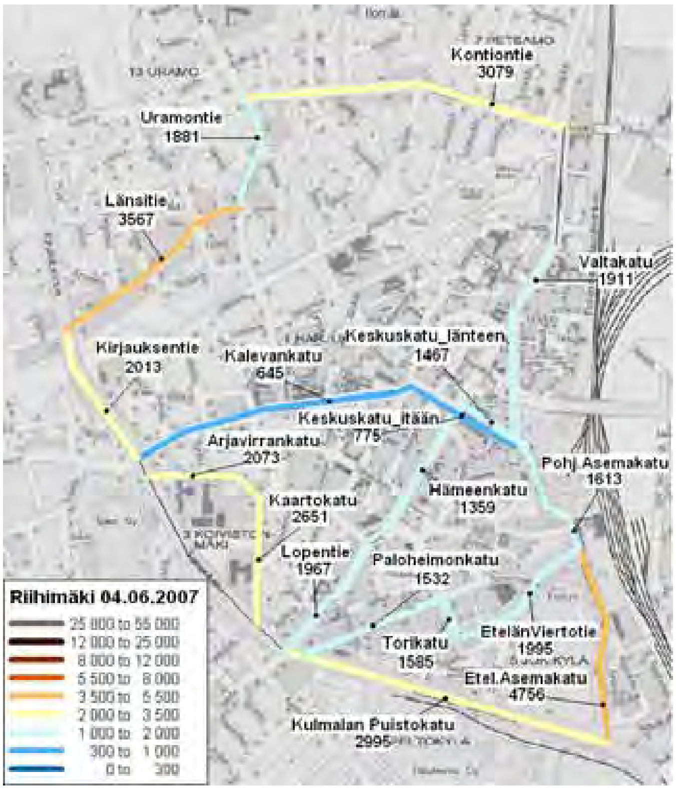


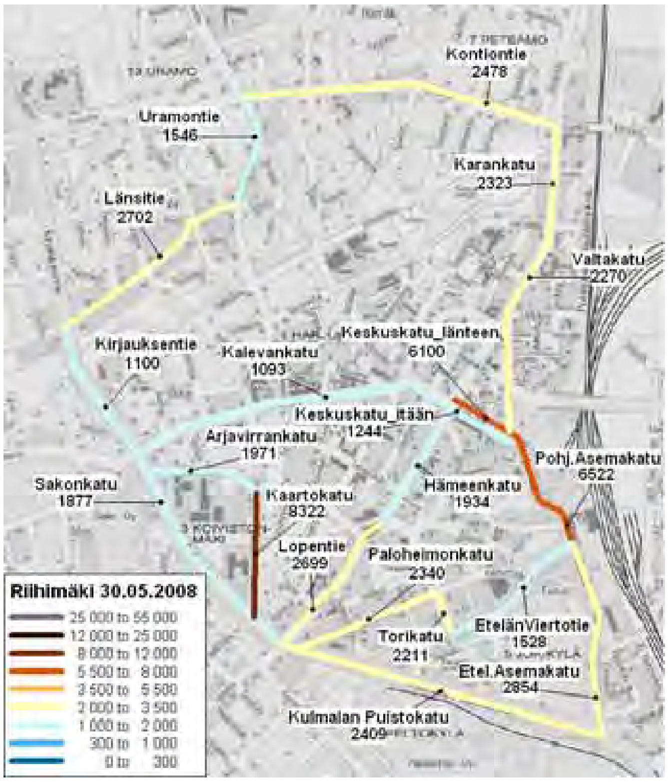


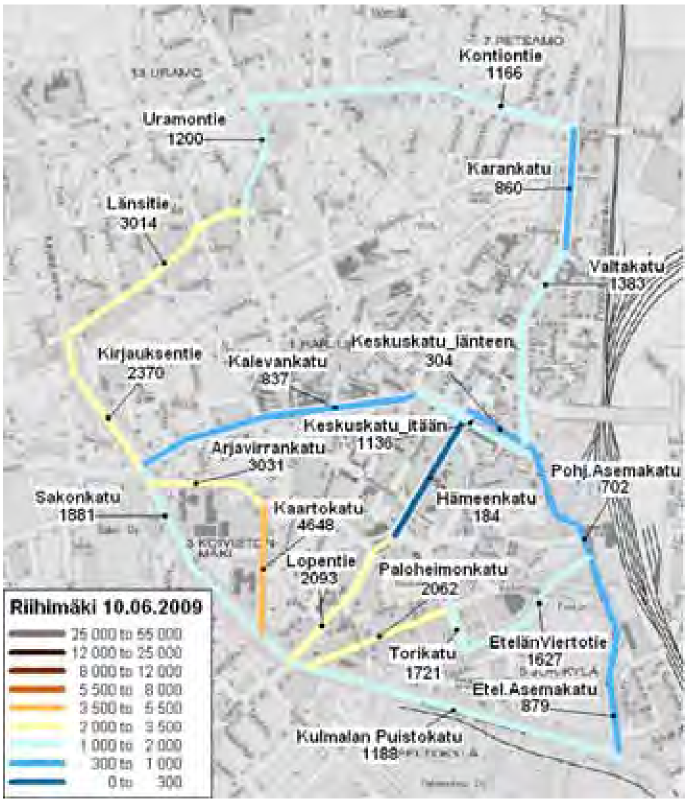


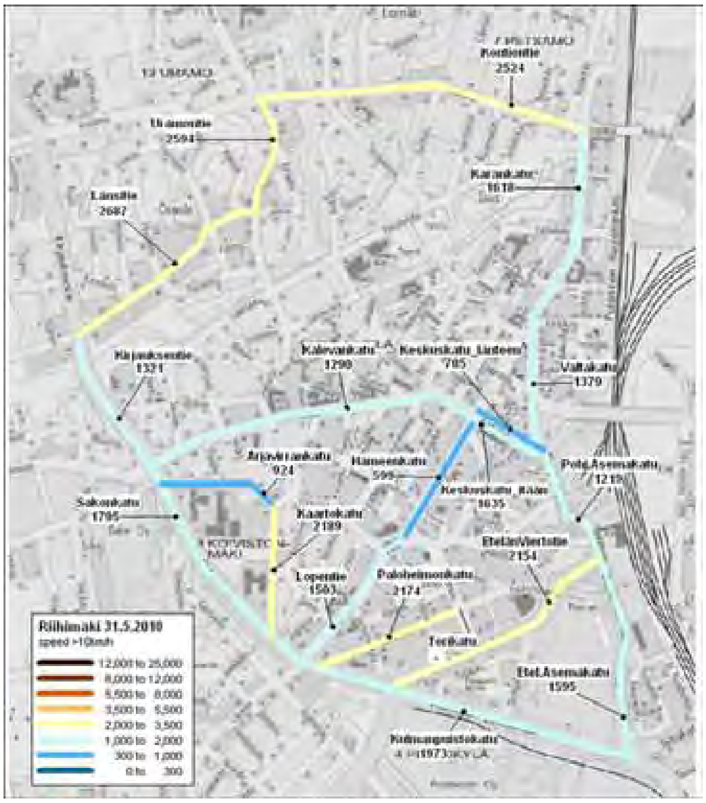


Riihimäki route – Late spring/early summer (after the cleaning) 2007–2010

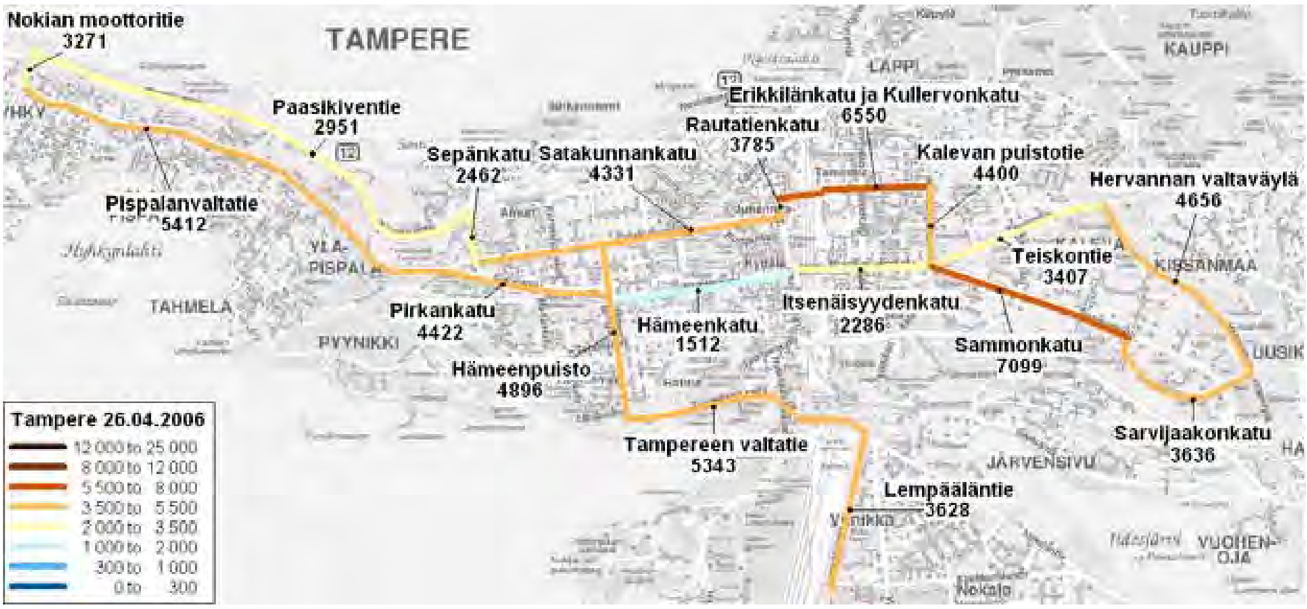


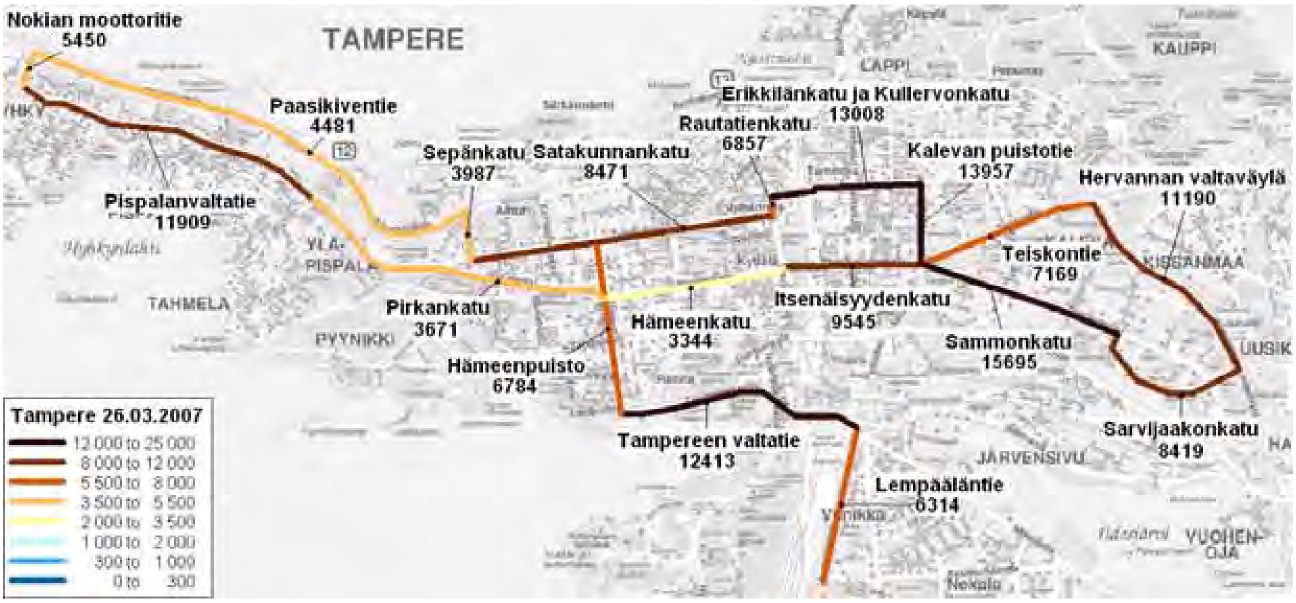


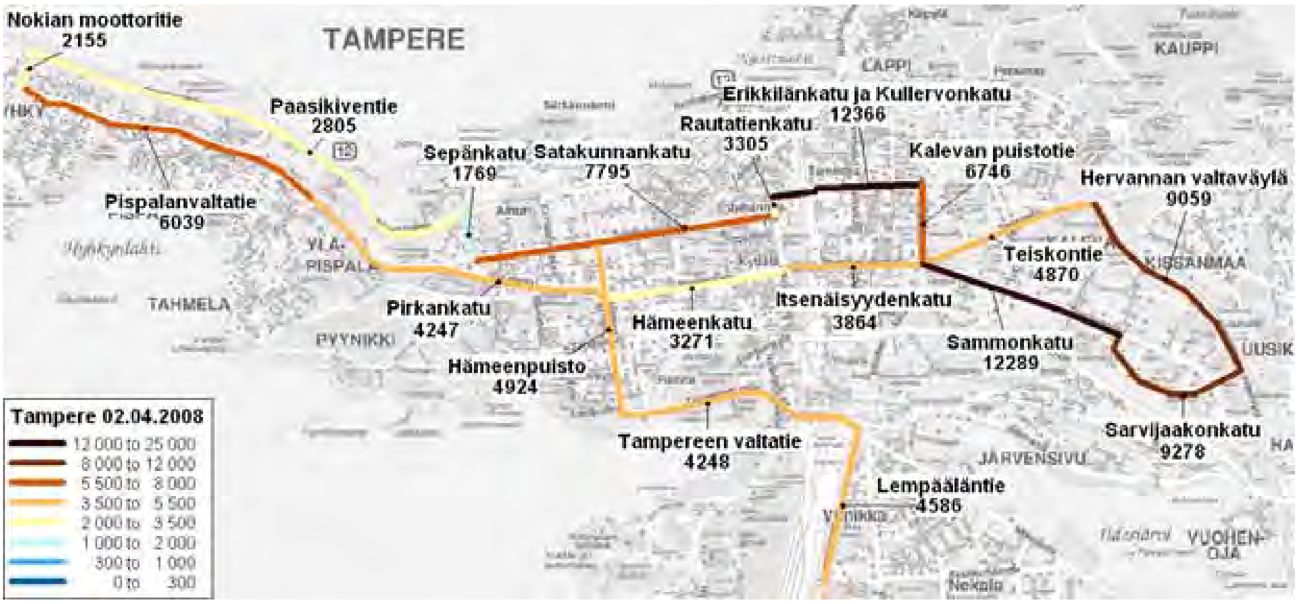




Tampere route - Early spring 2006–2010

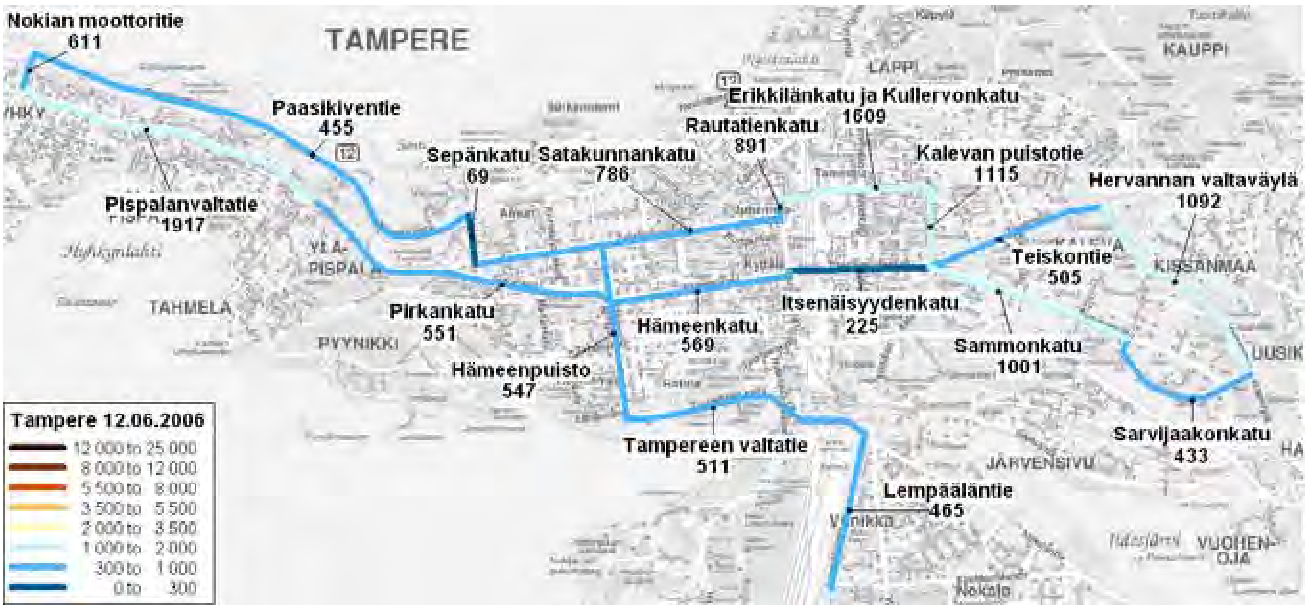



TAMPERE
Nokian moottoritie
5450
Paasikiventie
4481
Pispalanvaltatie
11909
Sepänkatu
3987
Satakunnankatu
8471
Rautatienkatu
6857
Erikkilänkatu ja Kullervonkatu
13008
Kalevan puistotie
13957
Hervannan valtaväylä
11190
Teiskontie
7169
Itsenäisyydenkatu
9545
Sammonkatu
15695
Pirkankatu
3671
Hämeenkatu
3344
Hämeenpuisto
6784
Tampereen valtatie
12413
Sarvijaakonkatu
8419
Lempääläntie
6314
Tampere 26.03.2007
12 000 to 25 000
8 000 to 12 000
5 500 to 8 000
3 500 to 5 500
2 000 to 3 500
1 000 to 2 000
300 to 1 000
0 to 300

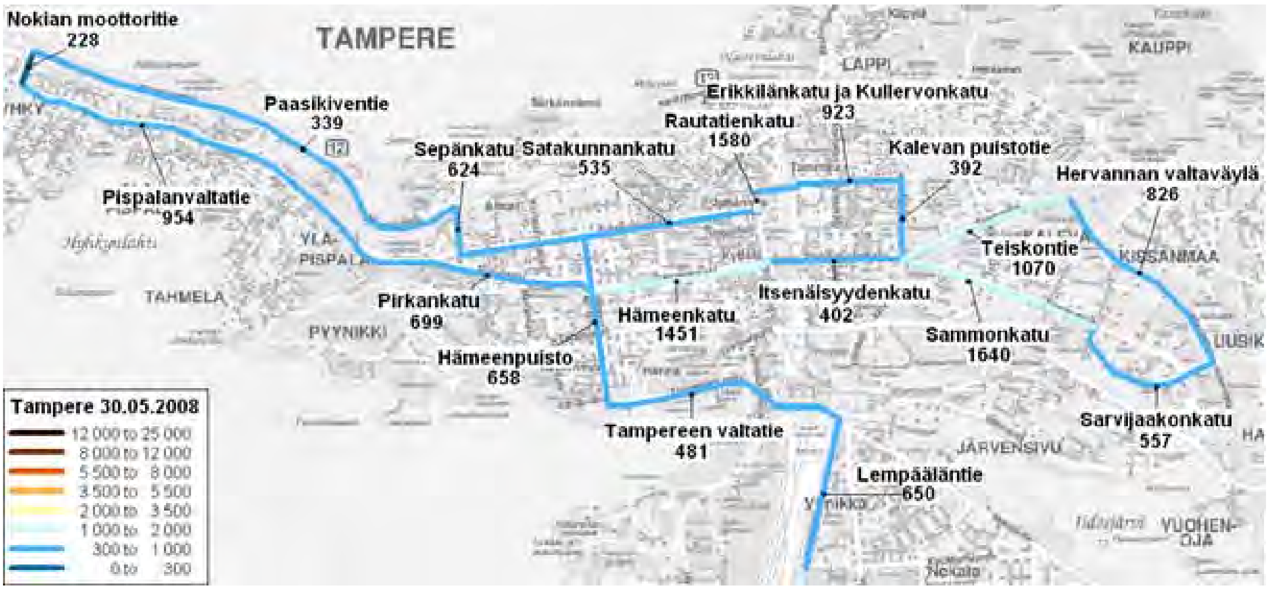

TAMPERE
Nokian moottoritie
2155
Paasikiventie
2805
Pispalanvaltatie
6039
Sepänkatu
1769
Satakunnankatu
7795
Rautatienkatu
3305
Erikkilänkatu ja Kullervonkatu
12366
Kalevan puistotie
6746
Hervannan valtaväylä
9059
Teiskontie
4870
Itsenäisyydenkatu
3864
Sammonkatu
12289
Pirkankatu
4247
Hämeenkatu
3271
Hämeenpuisto
4924
Tampereen valtatie
4248
Sarvijaakonkatu
9278
Lempääläntie
4586
Tampere 02.04.2008
12 000 to 25 000
8 000 to 12 000
5 500 to 8 000
3 500 to 5 500
2 000 to 3 500
1 000 to 2 000
300 to 1 000
0 to 300


TAMPERE
Nokian moottoritie
893
Paasikiventie
1237
Pispalanvaltatie
2148
Sepänkatu
1284
Satakunnankatu
3661
Rautatienkatu
3833
Erikkilänkatu ja Kullervonkatu
4520
Kalevan puistotie
2316
Hervannan valtaväylä
1994
Teiskontie
1913
Itsenäisyydenkatu
2536
Sammonkatu
4676
Pirkankatu
2122
Hämeenkatu
3407
Hämeenpuisto
1914
Tampereen valtatie
2013
Sarvijaakonkatu
1979
Lempääläntie
2360
Tampere 26.03.2009
12 000 to 25 000
8 000 to 12 000
5 500 to 8 000
3 500 to 5 500
2 000 to 3 500
1 000 to 2 000
300 to 1 000
0 to 300

Tampere route – Late spring/early summer (after the cleaning) 2006–2010

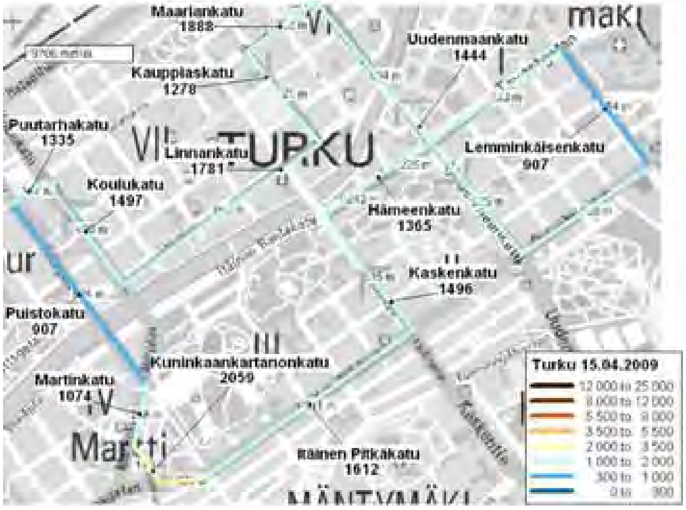



TAMPERE
Nokian moottoritie
633
Paasikiventie
684
Pispalanvaltatie
1231
Sepänkatu
104
Satakunnankatu
304
Rautatienkatu
977
Erikkilänkatu ja Kullervonkatu
901
Kalevan puistotie
984
Hervannan valtaväylä
2044
Teiskontie
625
Pirkankatu
758
Hämeenkatu
2050
Itsenäisyydenkatu
368
Sammonkatu
1399
Hämeenpuisto
297
Tampereen valtatie
567
Sarvijaakonkatu
841
Lempääläntie
623
TAHMELA
PYYNIKKI
LAPPI
KAUPPI
KISSANMAA
JÄRVENSIVU
Tampere 04.06.2007
12 000 to 25 000
8 000 to 12 000
5 500 to 8 000
3 500 to 5 500
2 000 to 3 500
1 000 to 2 000
300 to 1 000
0 to 300


TAMPERE
Nokian moottoritie
228
Paasikiventie
339
Pispalanvaltatie
954
Sepänkatu
624
Satakunnankatu
535
Rautatienkatu
1580
Erikkilänkatu ja Kullervonkatu
923
Kalevan puistotie
392
Hervannan valtaväylä
826
Teiskontie
1070
Pirkankatu
699
Hämeenkatu
1451
Itsenäisyydenkatu
402
Sammonkatu
1640
Hämeenpuisto
658
Tampereen valtatie
481
Sarvijaakonkatu
557
Lempääläntie
650
TAHMELA
PYYNIKKI
LAPPI
KAUPPI
KISSANMAA
JÄRVENSIVU
Tampere 30.05.2008
12 000 to 25 000
8 000 to 12 000
5 500 to 8 000
3 500 to 5 500
2 000 to 3 500
1 000 to 2 000
300 to 1 000
0 to 300


TAMPERE
Nokian moottoritie
653
Paasikiventie
492
Pispalanvaltatie
1327
Sepänkatu
30
Satakunnankatu
659
Rautatienkatu
1021
Erikkilänkatu ja Kullervonkatu
2490
Kalevan puistotie
1528
Hervannan valtaväylä
1499
Teiskontie
1283
Pirkankatu
1521
Hämeenkatu
2465
Itsenäisyydenkatu
784
Sammonkatu
3048
Hämeenpuisto
749
Tampereen valtatie
535
Sarvijaakonkatu
667
Lempääläntie
912
TAHMELA
PYYNIKKI
LAPPI
KAUPPI
KISSANMAA
JÄRVENSIVU
Tampere 02.06.2009
12 000 to 25 000
8 000 to 12 000
5 500 to 8 000
3 500 to 5 500
2 000 to 3 500
1 000 to 2 000
300 to 1 000
0 to 300

Turku route - Early spring 2008–2009



Turku route – Late spring/early summer (after the cleaning) 2008 - 2009

Vantaa route - Early spring 2006–2010

Vantaa route – Late spring/early summer (after the cleaning) 2006–2010

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