Radio-frequency electromagnetic field (RF-EMF) exposure levels in different European outdoor urban environments in comparison with regulatory limits

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ABSTRACT

Background

Concerns of the general public about potential adverse health effects caused by radio-frequency electromagnetic fields (RF-EMF) led authorities to introduce precautionary exposure limits, which vary considerably between regions. It may be speculated that precautionary limits affect the base station network in a manner that mean population exposure unintentionally increases.

Aims

The objectives of this multicenter study were to compare mean exposure levels in outdoor areas across four different European cities and to compare with regulatory RF-EMF exposure levels in the corresponding areas.

Methods

We performed measurements in the cities of Amsterdam (the Netherlands, regulatory limits for mobile phone base station frequency bands: 41-61 V/m), Basel (Switzerland, 4-6 V/m), Gent (Belgium, 3-4.5 V/m) and Brussels (Belgium, 2.9-4.3 V/m) using a portable measurement device. Measurements were conducted in three different types of outdoor areas (central and non-central residential areas and downtown), between 2011 and 2012 at 12 different days. On each day, measurements were taken every 4 seconds for approximately 15 to 30 minutes per area. Measurements per urban environment were repeated 12 times during one year.

Results

Arithmetic mean values for mobile phone base station exposure ranged between 0.25 V/m (Basel) and 0.44 V/m (Amsterdam) in all outdoor areas combined. The 95th percentile varied between 0.46 V/m (Basel) and 0.66 V/m (Basel and Amsterdam) and the 99th percentile between 0.81 V/m (Basel) and 1.20 V/m (Brussels).

Conclusions

All exposure levels were far below international reference levels proposed by ICNIRP (International Commission on Non-Ionizing Radiation). Our study did not find indications that lowering the regulatory limit results in higher mobile phone base station exposure levels.

KEY WORDS

Portable exposure meter; Radio-frequency electromagnetic fields (RF-EMF); Regulatory limits; Exposure assessment

1. INTRODUCTION

The introduction and development of wireless telecommunication technologies has led to a substantial increase in radio-frequency electromagnetic field (RF-EMF) exposure in the last two decades (Frei et al. 2009; Joseph et al. 2010; Röösli et al. 2010a), resulting in a fundamental change of population-based exposure patterns to RF-EMF.

This growth and ubiquitous use of wireless technology in society has raised public concerns regarding potential adverse health effects from RF-EMF exposure (Blettner et al. 2008; Schreier et al. 2006). This has pressured some countries (e.g., Switzerland and Belgium) to lower the precautionary regulatory exposure limits, whereas other countries (e.g., the Netherlands) retained exposure limits as proposed by the International Commission on Non-Ionizing Radiation Protection (ICNIRP).

Intuitively, lowering standard limits is expected to decrease exposure of the population by lowering the output powers of antennas. However, lower regulatory limits could affect the base station network configuration in a way that more base stations might be required to compensate lower output powers of antennas. Although a denser network may reduce maximum exposure levels, total average exposure of the population may increase because of a higher network density. Furthermore, in a denser network mast height may be lowered and/or tilt of the antennas may be increased, producing higher RF-EMF exposure levels at the surface where people are. Thus, precautionary limits might affect exposure even in a counter-intuitive way and result in an increased mean exposure in the everyday environment where people spend their time. A denser network is also expected to affect the output power of mobile phones: the phones' output power is optimized, i.e., reduced, while an optimal connection can be maintained. However, if handovers (i.e. changing the communicating base station during an active call while moving) occur (Lin et al. 2002; Urbinello and Röösli 2013), the output power of GSM (Global System for Mobile Communication) mobile phones return to the maximum (Erdreich et al. 2007; Gati et al. 2009) since they radiate with full power during connection establishment and down-regulate as soon as connection has been established. UMTS (Universal Mobile Telecommunication System) phones, in contrast, have an adaptive regulation and thus radiate with lower power. The denser the network, the more handovers or location area updates have to be expected. A recent European study with software modified mobile phones found that the average output power was approximately 50% of the maximal value, and that output power varied up to a factor 2 to 3 between countries and network operators (Vrijheid et al. 2009).

So far, an evaluation of the impact of standard limits on the population's exposure has not been evaluated since comparable measurement data from countries with different standard limits were lacking. Such a comparison needs a substantial amount of data from different areas that are collected with the same methodology. Different studies have been conducted comparing RF-EMF exposure levels with measurement devices (exposimeter) in different microenvironments and countries (Bolte et al. 2008; Frei et al. 2009; Joseph et al. 2010; Joseph et al. 2008; Thuróczy et al. 2008; Viel et al. 2009). However, in these studies methods differed between cities concerning recruitment process of volunteers performing measurements, data analysis and/or data collection procedures: e.g. in some studies, participants carried an exposimeter during their activities and were allowed to use their own mobile phone, which influences RF-EMF exposure even if the mobile phone is in stand-by mode (Urbinello and Röösli 2013); while in others they were not allowed to do so.

The objectives of this multi-center study were to compare RF-EMF mean exposure levels in different outdoor urban environments and to evaluate the impact of regulatory limits on RF-EMF outdoor exposure levels across European cities in terms 95^{th} and 99^{th} percentiles.

2. METHODS

Data collection took place in several European cities, namely Basel (Switzerland), Ghent and Brussels (Belgium), and Amsterdam (the Netherlands). All measurements are based on a common measurement protocol.

2.1. Definition of urban environments and data collection

Measurements were conducted in different outdoor urban environments for typically 15 to 30 minutes per area. The type of area was matched across countries in order to enable a direct comparison. We included central residential areas, located in zones with higher buildings (4 to 5 floors) and considerable road traffic as well as numerous people on the sidewalks. Non-central residential areas are situated outside the city centre in quiet residential zones with building heights of 2 to 3 floors and relatively large proportions of green space compared to central residential and downtown areas. Downtown areas represent the city center with a busy pedestrian zone.

We performed two separate personal measurement studies. In study 1, repeated measurements were done in Basel (denoted as Basel 1), Ghent and Brussels on either Wednesday or Thursday between April 2011 and March 2012. Data were collected in the first week of each month in Basel, and preferably in the third week of each month in Ghent and Brussels. Measurements were shifted by one week in case measurements could not be performed in the first and third week, respectively. The exposimeter was carried on the rear of the body in a bag.

In study 2, repeated measurements on the same days were carried out in Basel (denoted as Basel 2) and Amsterdam every second week on Wednesday and Thursday between 10^{th} November 2010 and 27^{th} January 2011 (Figure 1) (Urbinello et al., 2013). In Basel, the exposimeter was placed in a pushchair cart and in Amsterdam in a bike cart. In this way, measurements were taken with a distance of around one meter away from the body and at a height of one meter above ground. In study 2, the paths in Basel differed from the paths in study 1, but the areas were the same.

All measurements were conducted by the same study assistant in all cities except in Amsterdam. The mobile phone of the person taking the measurements was turned off while measuring and all measurements were carried out during daytime. Figure 1 summarizes the study procedure in the different cities.

2.2. Study instruments

RF-EMF measurements in Basel, Ghent and Brussels were performed using the EME Spy 120 (ES 120) from SATIMO (SATIMO, Courtaboeuf, France, http://www.satimo.fr/), enabling to quantify personal exposure at 12 separate frequency bands. Frequency bands for the ES 120 range from FM radio (frequency modulation; 88–108 MHz) to W-LAN (wireless local area network; 2.4–2.5 GHz). In Amsterdam, the EME Spy 140 (ES 140) was used. The measurement interval was set to 4 seconds in order to collect a large number of data points.

A GPS (Global Positioning System) logger (GPS Sport 245 from Holux) was used to log locations at ten second intervals in Basel, Ghent and Brussels, and a Garmin Oregon 550

(Garmin Inc., Olathe, KS, USA) in Amsterdam. The Swiss Federal Institute of Technology (ETH Zurich) developed a smart phone based application to log the time in all urban environments by registering start and ending of measurements in a specific microenvironment enabling the linkage of measurements to the specific area.

All devices were calibrated in September 2010, April 2011, and December 2011.

2.3. Statistical analyses

The lower detection limit of the ES 120 is 0.0067 mW/m^2 and 0.000067 mW/m^2 for the ES 140 (corresponding to electric field strengths of 0.05 V/m and 0.005 V/m, respectively). In order to have comparable results for Amsterdam, data were censored at 0.05 V/m and arithmetic mean values, with 95% Confidence interval (CI), for each area and frequency per measurement day were calculated using the robust regression on order statistics (ROS) algorithm (Röösli et al. 2008). If less than three measurements were above the detection limit for a given area and frequency band, the arithmetic mean value was set to 0.000265 mW/m^2 (0.01 V/m). All calculations were conducted using power flux density values (i.e. power flux per area, denoted as power densities) in W/m^2 and then back-transformed to electric field strengths (V/m). For the analyses we considered three relevant frequency groups: i) total RF-EMF exposure: sum of mean power densities of all frequency bands without DECT (Digital Enhanced Cordless Telecommunications). We excluded DECT since it is not a relevant source in outdoor areas and calibration showed cross-talk with nearby bands; ii) mobile phone base station exposure: sum of mean power densities of all downlink frequencies (GSM900 (925-960 MHz), GSM1800 (1805-1880 MHz) and UMTS (2110-2170 MHz)); and iii) mobile phone handset exposure: sum of mean power densities of all uplink frequencies (GSM900 (880-915 MHz), GSM1800 (1710-1785 MHz) and UMTS (1920-1980 MHz)).

The data distributions including the occurrence of high exposure values in the four cities were evaluated with the cumulative density function (CDF).

2.4. Regulatory limits

In the Netherlands, regulatory levels are adopted from the ICNIRP guidelines (ICNIRP 1998) (Table 1). The ICNIRP regulatory limits are frequency-dependent; 41 V/m for 900 MHz, 58 V/m for 1800 MHz and 61 V/m for 2100 MHz.

In Switzerland, the ICNIRP guidelines are also implemented. In addition, frequency-dependent precautionary exposure limits have been set (ONIR 1999). The ONIR (Ordinance relating to Protection from Non-Ionising Radiation) limits apply to the emission from one single base station and are only relevant for sensitive areas where persons spend most of their time, such as residences, schools, kindergartens, hospitals, nursing homes, workplaces, children's and school playgrounds. The ONIR precautionary limits of electric field strengths are 10 times lower than the ICNIRP guidelines (Table 1). In Ghent, precautionary regulatory exposure limits of the Flemish region (Ordinance of the Flemish Region of Nov. 2010) are valid for exposure per base station and apply to indoor places and children's playgrounds: 3 V/m at 900 MHz, 4.2 at 1800 MHz and 4.5 V/m at 2100 MHz (Table 1). These precautionary regulatory limits are estimated by calculating $0.1 * \sqrt{f}$ (with f as the frequency in Hz) for the frequency range between 400 MHz and 2000 MHz and 4.5 V/m for >2000MHz to 10 GHz. In Brussels, limits of the Brussels Capital Region (Ordinance of the Brussels Capital Region of 14 March 2007) are valid at all public places in total (i.e. cumulative exposure[1]); precautionary regulatory limits for frequencies between 400 MHz and 2000 MHz are calculated using the formula f/40,000 (W/m^2) (with f as the

[1] In Ghent, Flanders there is also a limit for cumulative exposure of 21 V/m (at 900 MHz, frequency dependent).

frequency in Hz; corresponds to $\sqrt{(f/40{,}000\ [W/m2] * 377)}$ on electric field strength). For frequencies between 2 GHz and 300 GHz, exposure values may not exceed 4.3 V/m (corresponds to 0.05 W/m^2 on power flux density level) (Table 1). According to the adopted limits in the different countries, regulatory exposure limits are most strict in Brussels and least stringent in Amsterdam (Table 1).

3. RESULTS

3.1. General results and cross-comparison between countries

In study 1, a total of 8,304 data points per frequency band were collected for Basel 1, 8,909 for Ghent and 8,165 for Brussels during one year for all outdoor areas combined. In study 2, we collected 16,401 and 22,532 measurements per frequency band in Basel and Amsterdam, respectively, over a period of three months for all areas combined.

Average total RF-EMF exposure over the whole study period and all outdoor areas combined varied between 0.25 V/m (Basel 2) and 0.44 V/m (Amsterdam). Highest values occurred in the downtown areas of all cities, ranging from 0.32 V/m (Ghent) to 0.58 V/m (Brussels), whereas exposure levels in residential areas (non-central and central residential) were slightly lower (0.16 V/m (Basel 2) to 0.42 V/m (Ghent)). Total RF-EMF exposure in outdoor areas was mainly driven by mobile phone base station radiation exposure causing levels between 0.22 V/m (Basel 2) and 0.41 V/m (Amsterdam) for all areas combined, whereby influence of mobile phone handsets was marginal: 0.06 V/m (Basel 1, Basel 2, and Ghent) to 0.17 V/m (Brussels) (Table 2).

3.2. Data distribution of high exposure levels and investigation of the impact of regulatory limits on RF-EMF exposure

In order to explore the distribution of high exposure levels, Figure 2 and Table 3 show the 95th and 99th percentiles. In central residential areas, the 95th percentile ranged between 0.27 V/m (99th percentile: 0.45 V/m) in Basel 1 and 0.73 V/m in Ghent (99th percentile: 1.37 V/m), in non-central residential areas between 0.29 V/m (0.61 V/m) in Ghent and 0.73 V/m (1.13 V/m) in Amsterdam. Highest exposure levels occurred in the downtown areas ranging between 0.52 V/m (Basel 2) and 0.94 V/m (Amsterdam) for the 95th percentile and between 0.87 V/m (Ghent and Basel 2) and 2.08 V/m (Brussels) for the 99th percentile (Table 3 and Figure 2c).

Figure 3 shows mobile phone base station exposure as a function of the corresponding regulatory limit for arithmetic means levels averaged over the entire study period. In the central residential area of Ghent (0.36 V/m) and downtown areas of Brussels (0.51 V/m) and Basel 2 (0.47 V/m) exposure levels were of similar magnitude as in Amsterdam (central residential area: 0.31 V/m; downtown: 0.51 V/m) despite the lower regulatory limits in Ghent, Brussels and Basel.

4. DISCUSSION

This paper analysed RF-EMF exposure in different outdoor areas and evaluated whether lower regulatory limits have an impact on ambient exposure across several European cities. In contrast to our speculation, our study did not find indications that lowering regulatory limits results in higher mobile phone base station exposure levels. Exposure levels were highly spatially variable and varied considerably between different areas within as well as between cities. For example, within city mobile phone base station exposure in Basel varied between 0.14 V/m (central residential area) and 0.47 V/m (downtown). Also, between cities substantial differences were observed for the same type of areas. In central residential areas mean exposure ranged from 0.14 V/m (Basel 1) to 0.36 (Ghent) V/m, in non-central residential areas from 0.15 V/m to 0.36 V/m

(Amsterdam) and in downtown areas from 0.27 V/m (Ghent) to 0.51 V/m (Brussels and Amsterdam).

4.1. Strengths and limitations

This is the first study investigating the impact of different regulatory limits on RF-EMF exposure in different outdoor environments using a standardized data collection procedure across four European cities. Previous international studies extracted data from multiple studies using different data collection or analysis procedures (Joseph et al. 2010), limiting a direct comparison between countries.

A further strength of our study was that the own mobile phone was turned off during measurements, enabling the association of mobile phone handset exposure to be attributable to other peoples' mobile phone which was not the case in previous studies (Frei et al. 2009; Viel et al. 2009).

Our study has also limitations; due to practical reasons we could not measure at the same time and apply the exact same procedures in all 4 cities. For instance, the exposimeter used for measurements in Amsterdam was not of the same type (ES 140) and differed in the lower detection limit from the exposimeter used in Belgium and Switzerland. However, we censored this data at the same detection limit as the data collected with the ES 120 (i.e. 0.05 V/m) to obtain comparable results and we excluded the two additional frequency bands (i.e. WiMax and W-LAN 5G) as well as DECT, which was excluded from all data due to cross-talk interferences (Lauer et al. 2010).

A further limitation is the inclusion of only four cities with three areas per city into the study. Thus, random data variability may play a role and additional data from more cities would allow drawing firmer conclusions.

Since we took all measurements on two working days (Wednesday and Thursday) and during daytime, we did not capture differences in exposure between working days and weekends, or between daytime and evening. However, we suspect that even though there could be differences in exposure levels at different times of the day; these are probably similar across the different cities. Furthermore, temporal variability has been found to be low across days of the week (Beekhuizen et al. 2013).

4.2. Interpretation

All RF-EMF exposure levels were far below ICNIRP reference levels. So far, no health effects could consistently be demonstrated below this level (Röösli et al. 2010b). Nevertheless, there is some uncertainty about long term health effects at low exposure levels and minimizing exposure to RF-EMF has been recommended (Berg-Beckhoff et al. 2009; Blettner et al. 2008; Neubauer et al. 2007; WHO 2010) and many countries have thus introduced precautionary limits. Whether such measures are effective to reduce population exposure has not been evaluated so far. The consequences of precautionary limits on the exposure situation are difficult to predict because more stringent regulations affect the base station network configuration. It seems plausible that high exposure values are reduced by precautionary limits but mean exposure may even be increased due to the higher network density with more microcells installed close to where the population spends its time. Our study, however, did not find any indications for this. Conversely, across all areas mean exposure levels were highest in Amsterdam which might indicate that precautionary levels indeed reduce population's mobile phone base station exposure. However, in area specific comparisons, levels in Amsterdam were similar to other cities except for the non-central residential area. The most relevant exposure effect if more base stations are installed might be the exposure reduction from the own mobile phone due to an optimized power control.

However, our study did not find any indications that uplink exposure levels from mobile phones were related to the level of the regulatory limits, although in order to accurately assess personal exposure, other techniques would be needed to evaluate whether the base station network configuration affects the output power of the phones.

Interestingly, also high exposure levels (95^{th} and 99^{th} percentiles) were not related to the level of the regulatory limits as one would primarily expect. The 99^{th} percentile was highest in Brussels, where most stringent regulatory limits were implemented. It has to be emphasized that our analysis is based on four cities only and alternative explanations should be considered. We tried to match characteristics of the selected areas across the cities. Nevertheless, the fact that exposure tended to be higher in Amsterdam may reflect the impact of population density, building characteristics or the choice of the measurement path in an area.

One could argue that the level of RF-EMF exposure in the population is not relevant as long as the reference levels, where health effects have been established, is not exceeded. However, in terms of long term health effects some uncertainty exists and thus minimizing exposure may reduce this uncertainty. For compliance with the regulatory limits most critical places are on the top floor of buildings, close and in direct line of sight of mobile phone base stations. As we measured only on street level, we cannot exclude that higher exposure levels can occur at such sites in cities with higher regulatory limits. If of concern, such high exposures could be reduced by limiting the output power of base stations.

4.3. Conclusion

Our study suggests that the introduction of precautionary limits does not unintentionally increase the mean RF-EMF exposure of the population.

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Conflict of interest

The authors declare no conflict of interest.

FIGURES

FIGURE 1: Overview of data collection periods in all study cities.

Footnotes to Fig. 1:

+ Data collection: 2 days per week/each month/during 24 months
Measurements included 3 outdoor areas: central and non-central residential areas and downtown.
*Data collection: 2 days per week/each 2 weeks/during 3 months
Measurements included 3 outdoor areas: central and non-central residential areas and downtown.

FIGURE 2: Cumulative density function (CDF) plots of the total downlink electric field strength (V/m) for all outdoor areas combined (a), for central residential (b), non-central residential (c) and downtown (d) areas.

FIGURE 3: Scatter plots indicating mobile phone base station exposure levels with corresponding 95% confidence intervals across all cities in relation to regulatory limits for all outdoor areas combined (a), central residential area (b), non-central residential area (c) and downtown (d).

TABLES

TABLE 1: National and local directives of regulatory RF-EMF exposure limits for the four cities.

Frequency	Basel[1]	Gent[2]	Brussels[3]	Amsterdam[4]
900 MHz	4 V/m	3 V/m	2.9 V/m	41 V/m
1800 MHz	6 V/m	4.2 V/m	4.1 V/m	58 V/m
2100 MHz	6 V/m	4.5 V/m	4.3 V/m	61 V/m

[1]Regulatory exposure limit per base station for sensitive areas: living rooms, school rooms, kindergarten, hospitals, nursing homes, places of employment, children's and school playgrounds.
[2]Regulatory exposure limit per antenna: valid for indoor places and children's playgrounds.
These regulatory limits are estimated by calculating $0.1 * \sqrt{f}$ (with f as the frequency in Hz) for the frequency range between 400 MHz and 2 GHz and 4.48 V/m for 2 GHz to 10 GHz.
GHz. There is also a limit for cumulative exposure of 21 V/m (at 900 MHz, frequency dependent).
[3]Regulatory exposure limit for cumulative RF-EMF exposure: valid at all public availability places (exceptions for various technologies).
[4]Regulatory exposure limit for cumulative RF-EMF exposure.

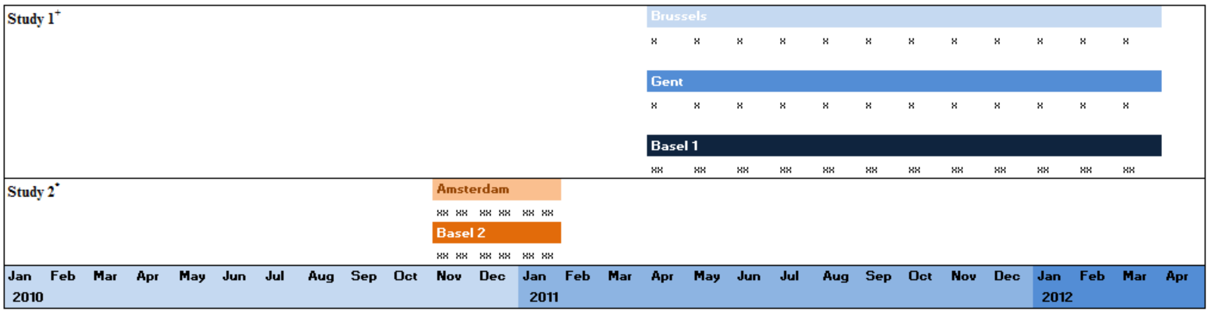
TABLE 2: Summary statistics of all frequency bands combined, mobile phone base station (downlink) and handset radiation (uplink) for each city and outdoor area, ordered by increasing regulatory limit. Values are displayed as electric field strength (V/m).

	All outdoor areas combined Arithmetic mean (95% CI)	Central residential area Arithmetic mean (95% CI)	Non-central residential area Arithmetic mean (95% CI)	Downtown Arithmetic mean (95% CI)
Total				
Brussels	0.41 (0.36, 0.46)	0.39 (0.13, 0.53)	0.24 (0.20, 0.27)	0.58 (0.49, 0.65)
Gent	0.32 (0.29, 0.34)	0.42 (0.39, 0.46)	0.17 (0.15, 0.18)	0.32 (0.29, 0.35)
Basel 1	0.33 (0.28, 0.37)	0.16 (0.14, 0.18)	0.21 (0.17, 0.25)	0.49 (0.42, 0.54)
Basel 2	0.25 (0.24, 0.26)	0.26 (0.05, 0.37)	0.21 (0.19, 0.22)	0.34 (0.30, 0.38)
Amsterdam	0.44 (0.43, 0.45)	0.37 (0.35, 0.40)	0.40 (0.38, 0.42)	0.57 (0.55, 0.59)
Total downlink				
Brussels	0.35 (0.29, 0.39)	0.22 (0.17, 0.25)	0.23 (0.19, 0.26)	0.51 (0.41, 0.59)
Gent	0.27 (0.25, 0.29)	0.36 (0.33, 0.39)	0.15 (0.14, 0.16)	0.27 (0.25, 0.29)
Basel 1	0.31 (0.27, 0.35)	0.14 (0.12, 0.16)	0.20 (0.16, 0.24)	0.47 (0.40, 0.53)
Basel 2	0.22 (0.21, 0.23)	0.18 (0.16, 0.19)	0.20 (0.19, 0.21)	0.30 (0.30, 0.31)
Amsterdam	0.41 (0.40, 0.43)	0.31 (0.28, 0.33)	0.36 (0.34, 0.38)	0.51 (0.49, 0.52)
Total uplink				
Brussels	0.17 (0.05, 0.24)	0.27 (0, 0.45)	0.04 (0.02, 0.05)	0.20 (0.16, 0.23)
Gent	0.06 (0.04, 0.08)	0.04 (0.03, 0.04)	0.03 (0.02, 0.03)	0.11 (0.06, 0.14)
Basel 1	0.06 (0.05, 0.07)	0.05 (0.04, 0.06)	0.02 (0.02, 0.03)	0.09 (0.07, 0.10)
Basel 2	0.06 (0.05, 0.06)	0.18 (0, 0.32)	0.07 (0.00, 0.11)	0.14 (0.00, 0.22)
Amsterdam	0.09 (0.08, 0.10)	0.16 (0.14, 0.18)	0.12 (0.11, 0.12)	0.17 (0.16, 0.18)

TABLE 3: Overview of total RF-EMF peak exposure values for the 95th and 99th percentile in outdoor areas. Values are displayed as electric field strength (V/m).

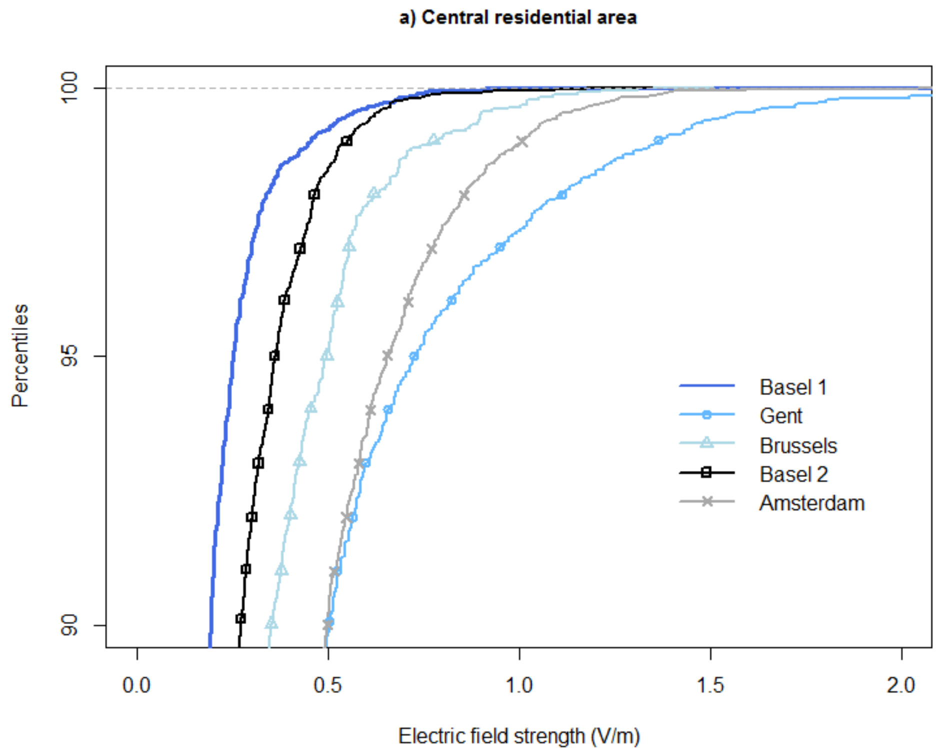
	All areas combined	Central residential area	Non-central residential area	Downtown
95 Percentile				
Basel 1	0.66	0.27	0.48	0.89
Gent	0.53	0.73	0.29	0.54
Brussels	0.66	0.50	0.44	0.92
Basel 2	0.46	0.36	0.34	0.52
Amsterdam	0.82	0.66	0.73	0.94
99 Percentile				
Basel 1	1.08	0.45	0.83	1.40
Gent	1.03	1.37	0.61	0.87
Brussels	1.20	0.78	0.92	2.08
Basel 2	0.81	0.55	0.92	0.87
Amsterdam	1.14	1.01	1.13	1.27

Fig. 1



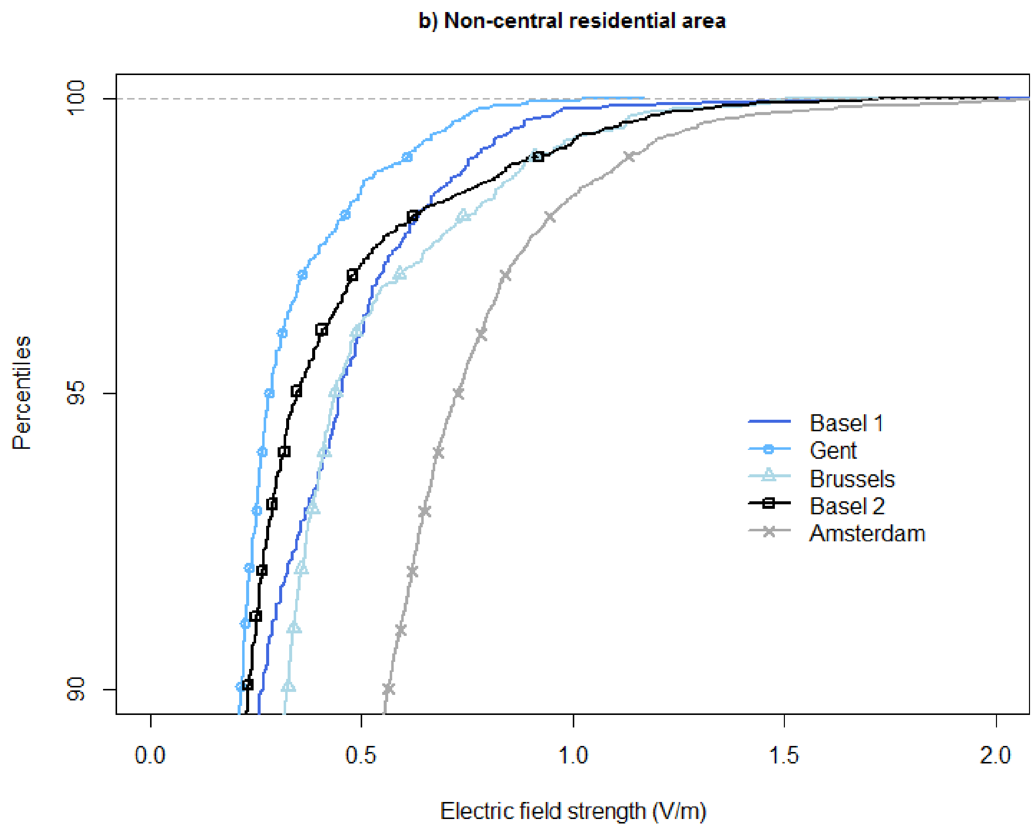
Study 1[+]
Brussels
Gent
Basel 1
Study 2[*]
Amsterdam
Basel 2
Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr May Jun Jul Aug Sep Oct Nov Dec Jan Feb Mar Apr
2010
2011
2012

Fig. 2a



a) Central residential area
Percentiles
100
95
90
0.0
0.5
1.0
1.5
2.0
Electric field strength (V/m)
Basel 1
Gent
Brussels
Basel 2
Amsterdam

Fig. 2b



b) Non-central residential area
Percentiles
100
95
90
0.0
0.5
1.0
1.5
2.0
Electric field strength (V/m)
Basel 1
Gent
Brussels
Basel 2
Amsterdam

Fig. 2c

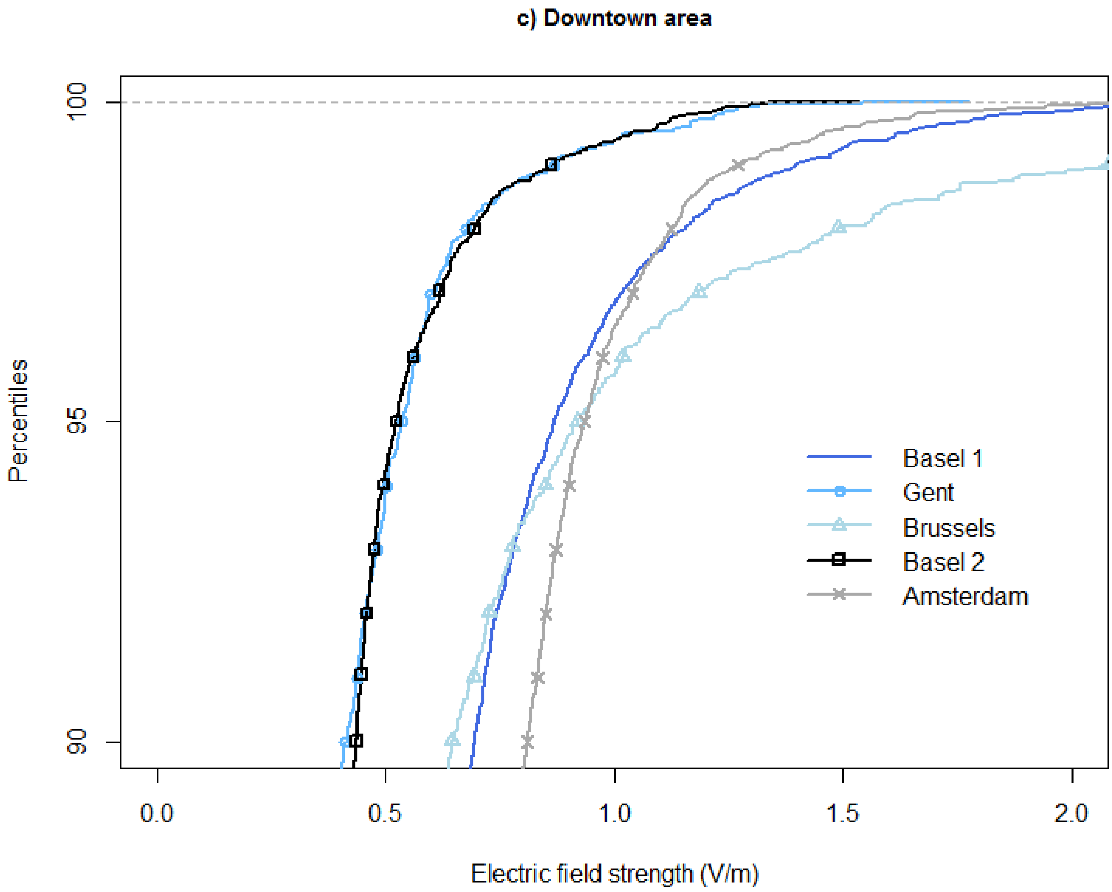
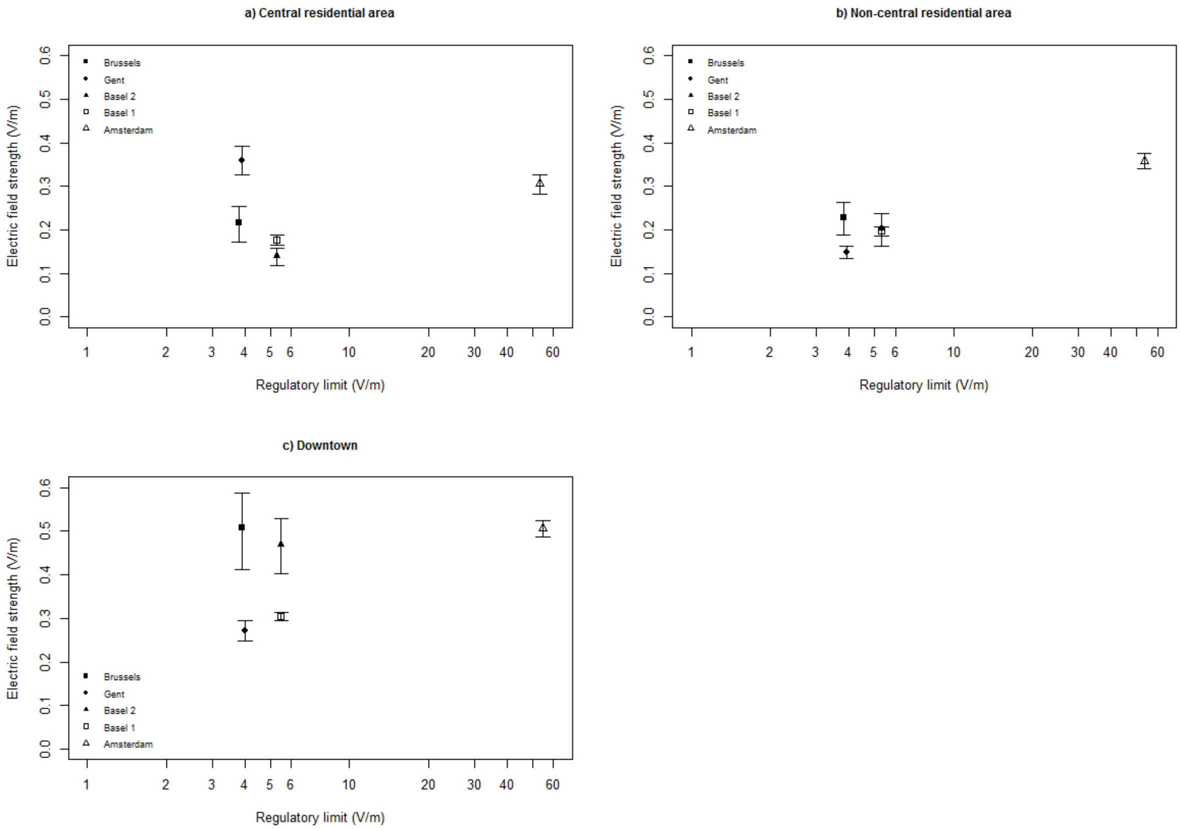

c) Downtown area
Percentiles
100
95
90
0.0
0.5
1.0
1.5
2.0
Electric field strength (V/m)
Basel 1
Gent
Brussels
Basel 2
Amsterdam

Fig. 3


a) Central residential area
Brussels
Gent
Basel 2
Basel 1
Amsterdam
Electric field strength (V/m)
0.0
0.1
0.2
0.3
0.4
0.5
0.6
1
2
3
4
5
6
10
20
30
40
60
Regulatory limit (V/m)
b) Non-central residential area
Brussels
Gent
Basel 2
Basel 1
Amsterdam
Electric field strength (V/m)
Regulatory limit (V/m)
c) Downtown
Brussels
Gent
Basel 2
Basel 1
Amsterdam
Electric field strength (V/m)
Regulatory limit (V/m)