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Living and Working in a Healthy Environment: How Sensor Research in Flanders can Help Measure and Monitor Exposure to Certain Environmental Factors

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1 ABSTRACT

People's daily living environment has an important influence on their physical and mental health. That living environment consists of many different components, as it is both a spatial or physical environment, and the result of many other processes (socio-cultural, economic context and individual characteristics and lifestyles). Overall, the pressure on the physical environment is very high, especially in densely populated and highly urbanised area’s such as Flanders, the northern part of Belgium. In urban environments, for instance, many spatial demands come together (space for housing, economy, mobility, green and blue infrastructures, etc.). The spatial layout of our cities can influence our health (e.g. whether or not we live nearby green spaces or in an environment that promotes active mobility, social contacts, if there are sources that impact the air quality, etc.), and of course our behaviour.

The relation between health, living and working environment and spatial planning is complex. Therefore, the Flemish Department of Environment & Spatial Development has prepared a framework in 2019 to better capture that complex relationship, which we will briefly discuss in this paper. Broadly speaking, a policy committed to healthy environments may choose to make interventions that protect people's health from certain external factors (e.g. air pollution or environmental noise) or that enable and promote healthy lifestyles (e.g. physical activity, food,…). Next to that, providing citizens with up to date information is an important task of the government.

In this paper, we discuss the research that the Environment and Health research team at the Flemish Department of Environment & Spatial Development conducts in order to measure human exposure to certain factors via sensors. Those particular factors were chosen mainly because they are part of themes around which the Flemish Department can make policy. We will consider three ongoing cases: measuring the quality of the indoor environment in different types of semi-public locations (such as schools, residential care centres, cultural centres,…), measuring radiofrequency radiation from fixed transmitting antennas in urban environments and measuring noise pollution. Partnering with international research & development organizations such as IMEC (Interuniversity Microelectronics Centre) and VITO (Flemish Institute for Technological Research), they supplied us with innovative and high-quality sensor technology. The sensors can transmit their measurement data in real time and participating parties can track the data on dashboards allowing immediate feedback and action when necessary. The results are intended to feed further research. Although not all case studies are equally advanced, we will conclude each one with possible policy actions.

Keywords: exposure, sensor network, living and working environment, real time data, health

2 WHY DOES A HEALTHY LIVING ENVIRONMENT MATTER AND HOW DOES IT RELATE TO SPATIAL PLANNING?

Health goes beyond the absence of disease: it is a state of physical, mental and social well-being. Health is an interplay of various personal factors such as genetics, age, lifestyle, as well as circumstances such as family and social network, working and living conditions and general socio-economic and cultural context. Health in All Policies (WHO, 2014) ensured that attention to health – in the broad sense of the word – in spatial policy and research is gradually increasing. In the Netherlands for example, the National Institute for Public Health and the Environment (RIVM) has contributed to the National Spatial Agenda (NOA) by describing the relationship between the living environment and health and by identifying future challenges and opportunities for healthy living environments (Rijksinstituut voor Volksgezondheid en Milieu, 2017).

The SARS-CoV-2 period made certain aspects of the healthy living and working environment all the more obvious: the need for high-quality green space, for social contacts, the need for good indoor air quality, etc. The way we organise and also use our available space (where we live, work, preserve nature, provide agricultural land, or deal with the built environment and density, transport, etc.) has an impact on our health. “Land use affects mobility, nature, green space, the quality of water, air and soil” (Teughels et al., 2022). But how can we grasp this more precisely?[1] In 2019 the Flemish Department of Environment & Spatial Development has prepared a framework to capture the complex relationship between health and factors that spatial planning can influence (Gommers et al, 2019). Figure 1 shows this relationship by using the intermediate step of healthy living and working environments. In those environments, the pressure on health by certain stressors (chemical, physical, biological) is minimised, physical safety is ensured as much as possible (from e.g. dangerous traffic situations, or natural disasters) and stress prevention plays an important role. In addition, people have access to healthy food, are invited to move actively and social interaction is made possible.

In terms of heath, the role of (spatial) policy might be seen as a combination of two themes: protecting or minimising health risks as much as possible and promoting healthy lifestyles and behaviour by providing the means to do so (e.g. active mobility, healthier nutrition).

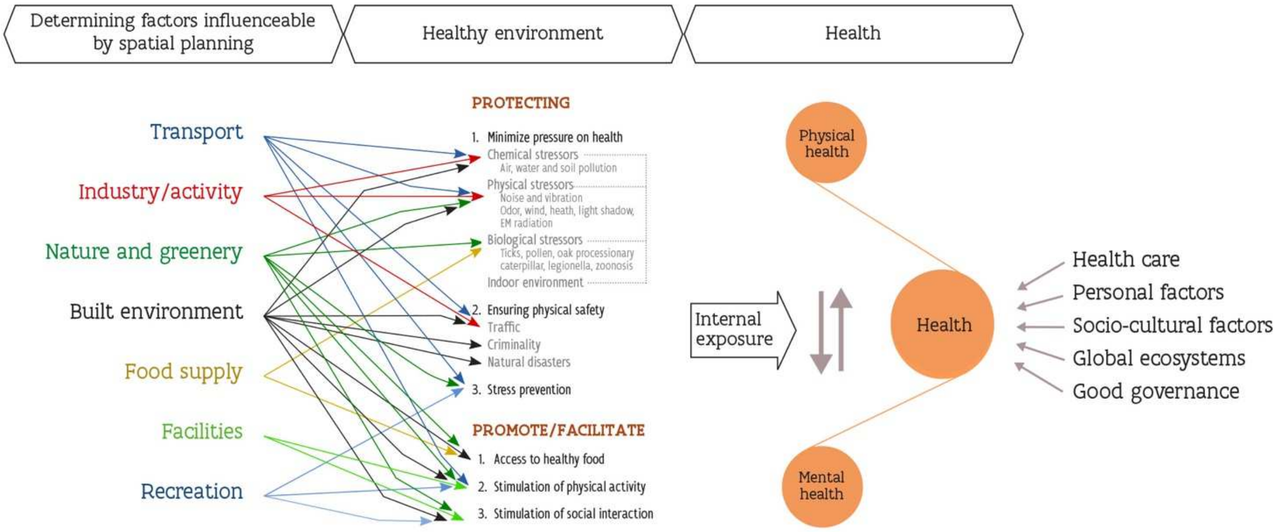

Fig. 1: the complex relation between health, healthy living and working environments and factors that spatial planning can influence (Teughels et al., 2022)

In line with the first theme around protection, the Environment and Health research team at the Flemish Department of Environment & Spatial Development has been working for years to measure human exposure to certain factors, mainly concerning the exposure to certain substances and poluents in the indoor air and in the ground (in the context of gardening) and exposure to sources of non-ionising radiation (radiofrequency

[1] Some caution about measurable impact between health and spatial impact is in order. It would seem that the scientific literature is far from unanimous on cause-and-effect relationships between spatial interventions and health effects. Links are demonstrated in cross-sectional studies where observations are made at a single point in time (e.g. between the walkability of a neighbourhood and activity levels of that neighbourhood). However, few longitudinal studies exist examining the effect of a measure on behaviour and health. (Gommers et al, p. 17)

(RF) and electromagnetic fields (EMF)). Next to this, the team is working around green infrastructure (types, proximity, perception,...) and human biomonitoring (including in the context of European Human Biomonitoring Network HBM4EU). Over the years, the team has accumulated a lot of knowledge on these various topics. However, this paper will focus on a few recent studies, which have a policy and societal question behind them. We will consider three ongoing cases. The first one is measuring the quality of the indoor environment in different types of semi-public locations (such as schools, residential care centres, cultural centres,…), which required rapid policy action in SARS-CoV-2 times. The second is measuring radiofrequency radiation from fixed transmitting antennas in urban environments, an important topic to follow up on, partly because oft he recent technological evolutions in telecommunications. And last is noise exposure, which is gaining importance internationally, as an factor with health impacts (e.g. Elmenhorst et al, 2019).

The finality of the different measurement campaigns varies: it is intended both to feed further research and legislative trajectories (e.g. in terms of standardisations, evaluation of standards), but also to provide very practical advice to participating partners (e.g. in terms of behaviour). Last but not least, in addition to raising awareness, it is also intended to provide correct information to people about certain important exposures, and so, reducing possible concerns.

3 RESEARCH ON HOW TO MEASURE EXPOSURE TO CERTAIN FACTORS

For the past 5 years, there was an accelerated technological development, which led to, among other things, the development of new types of sensors. Also in terms of data transmission, there were developments that allow instantaneous transmission of very large quantities of of data. This enables a different kind of measurement: where previously measurements were made with certain devices at a certain place and time, it is now possible to monitor a certain place for much longer, and collect more measurement data. In partnership with international research & development organizations such as IMEC (Interuniversity Microelectronics Centre) and VITO (Flemish Institute for Technological Research), we have started to develop different types of innovative and high-quality sensors. Depending on the factor we need to measure, the sensors can be placed outside or inside a building, or even on the human body. All sensors have in common that they can transmit their measurement data in real time and we collect the data in-house with the dataplatform Thingsboard. Interested parties can — in line with GDPR —track the data on dashboards allowing immediate feedback and action when necessary. For further global analysis, the data are anonymised. It is important to note that each sensor is calibrated at regular intervals, and updated when new technologies are available.

3.1 Indoor air quality & environment: the importance of people's behaviour and general knowledge at the start of building projects or reconversions

3.1.1 <u>Introduction</u>

In Figure 1, indoor air environment is a combination of chemical, physical and biological stressors, that can affect the health and well-being of its occupants or the people present in the room or building. It comes from three main sources: (1) the outside air (derived from how we organise our spatial lay-out, where we organise certain activities etc.), (2) the building materials of the built environment, especially when they consist of new building materials and at last (3) the sources inside the building envelope (people as a source of bio-effluents, including exhaled CO_2 and moisture but also bio-aerosols such as viruses and bacteria, furniture, smoking, use of ventilation when cooking, use of certain detergents or cleaning products etc). The building envelope functions between indoor and outdoor air quality. It can block certain pollutants from outside, but also keep certain pollutants from indoor sources inside, depending on the use of ventilation or aeration. Ventilation means that the air inside the builing is continuously refreshed, whereas aeration is briefly letting in a large amout of air by opening the doors or windows during a short amount of time. There exists four kinds of ventitalion types: (1) system A with natural supply and extraction, (2) system B — which is very rarely used in Flanders — with mechanical air supply and natural air extraction, (3) system C with natural air supply and mechanical air extraction and at last (4) system D with mechanical air supply and extraction.

In Flanders, people spend on average 85% of the day indoors. Because indoor air quality can affect the overall personal exposure of the building occupants, it is an important environmental determinant of health

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(High Health Council Belgium, 2017). Since 2007, the Flemish Department of Environment & Spatial Development has been conducting research regarding indoor air quality in homes and schools to inform policy. One of the main conclusions of the research regarding the relation between the outdoor and indoor air quality is that the indoor air contains a number of pollutants, usually with greater diversity, and for certain pollutants in higher concentrations than outdoors. In addition, the research shows that ventilation is important: rooms that are mechanically ventilated often have better air quality, than non-mechanically ventilated rooms.

3.1.2 Why indoor air quality matters: research and measuring campaigns with the sensor boxes

The main research question regarding indoor environement quality is the following: when is the indoor environment healthy, and what measures help to achieve a healthy situation? To answer this, the Flemish Department of Environment & Spatial Development, together with VITO, developed 15 sensor boxes to continuously measure a number of pollutants and other parameters (Lazarov et al., 2019). The sensor box measures particulate matter (PM), carbon dioxide (CO_2), carbon monoxide (CO), nitrogen dioxide (NO_2), volatile organic compounds (VOC), temperature and relative humidity.

Indoor air quality contains many different substances and parameters. With the corona pandemic between 2020 and 2022, a big focus in Belgium and in Flanders has been on CO2 values[2] and how efficiently ventilation is carried out. CO_2 values are considered a good proxy to monitor the quality of the ventilation and aeration, and an important preventive measure to limit potential contamination via airborne transmission of viruses. The higher the CO_2 concentration, the higher the concentration of aerosols (microdroplets produced by breathing) that can contain micro-organisms, bacteria and viruses. In the absence of ventilation in enclosed spaces, these micro-organisms accumulate in the room. Effective ventilation and aeration reduces the concentration of micro-organisms in a room, and so limiting their spread through the air. In addition, the concentration of all other chemical and biological agents with indoor sources also decreases with effective ventilation; this is beneficial for good indoor air quality – needed for general health and well-being.

During the corona period, public indoor locations, where many people congregated, needed quick insight into the situation of CO_2 levels, how ventilation was happening and whether it could also be improved. Locations with vulnerable populations and/or that bring many people together, such as schools, residential care centres for elder people, sport halls and concert or cultural event halls were particularly targeted. Therefore, the Department of the Environment & Spatial Development, together with other government partners (from several government departments, such as health, education and sports & culture), started several measurement campaigns from 2020, and the last one planned in schools in autumn 2023. The measurement campaigns varied between 2 weeks (for sports halls) to 4 months (for residential care centres), and continued in both summer and winter. The hypothesis is that people tend to ventilate and aerate less during cold winter days, as there are colder outdoor temperatures, and residents want to keep the draughts out (and reduce energy bills). On hot summer days too, people tend to keep the heat out, and so, doors and windows are kept closed.

We processed the results from the measurements in several final products: (1) each participant (school, residential care centre, cultural house) received a report with results that also contained concrete advice, (2) we made an (anonymised) overview report per sector, (3) we made a website for schools where they can get targeted advice via questions and (4) we gave direct input to our partner governments to make policy frameworks on ventilation. The Departement of Health adopted a policy regarding ventilation in residential care centres.

3.1.3 Results: giving pratical advise and input to policy makers

About the different measurement campaigns in the different sectors, we can draw some overarching conclusions. As Figure 2 illustrates, it is clear that people's behaviour has an impact on air quality: keeping windows and doors closed increases CO_2 levels in a classroom, opening them almost immediately has a

[2] The general guideline values were: if the CO_2 concentration is below 900 ppm (or 500 ppm above outdoor concentration), we consider the room well ventilated. In practice, 900 ppm for an adult engaged in standard light activity corresponds to a ventilation flow rate of 40 m³/h.person of fresh outdoor air. This means that an amount of fresh air of 40m³ should be provided per person present in the room per hour. For values between 900 and 1.200 ppm, measures are needed to fall back below 900 ppm. Exceedances above 1.200 ppm are in principle not allowed.

decreasing effect. This knowledge was very useful during the corona pandemic: we were able to provide immediate practical advice to e.g. schools, depending on their situation (e.g. new building, type of windows) and whether or not they had a mechanical ventilation system. It is also possible to link actions to certain trends from the graphs: e.g. for rooms without mechanical ventilation, one could match room occupancy to the surface of the open or tilted windows. The results gave direct input to the policy makers during the corona pandemic, e.g. wether or not the different sectors could implement certain measures regarding CO_2 levels.

Next to behaviour, there are the technical aspects of the ventilation or aeration. When installing the sensor boxes in the field, we noticed that people on site – regardless of the type of sector – often have little knowledge about the presence of a ventilation system or the way it works, and when was the last maintenance. Inspection, maintenance and correct settings of ventilation systems are necessary for it to function correctly. It seems essential to sensitise and inform various target groups, in particular architects, technical staff, school teachers, residents of care centres etc., about possible interventions that help improve indoor air quality. Attention to possible complaints from the occupants of the room (e.g. draught, heat, noise...) and obstacles for the staff (e.g. extra workload, possibility of safely opening windows) is recommended, as ventilation and aeration should not be at the expense of well-being. Architects are an important target group as well, as ventilation systems are usually installed when renovation or new construction takes place. It is therefore essential to attach importance to the implementation of ventilation from the start of the (re)construction project.

Based on our findings, we conclude that investing in demand-controlled (mechanical) ventilation ¬ a system that measures and monitors CO_2 values — contributes to improved air quality and consistently lowers CO_2 concentrations in the indoor environment, and so helps reduce airborne viral transmission. Generally, regardless of the outside temperature and the saison, we noticed that rooms that are equipped CO_2 ventilation systems of type D (mechanical air supply and extraction) are more effective at keeping the CO2 levels low, in comparison to the other types of ventilation systems. However, we have little insight into the reasons for the potential reduced performance of other ventilation types. This aspect will be included in upcoming studies in 2023, by conducting a technical screening of the ventilation systems.

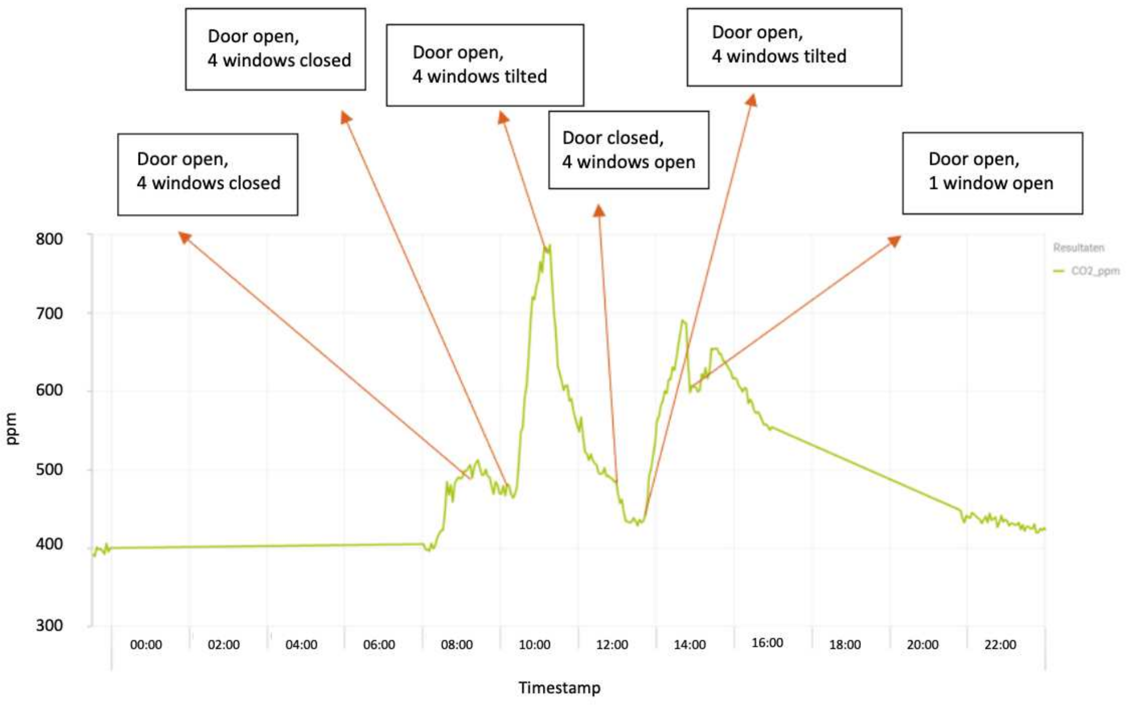

Fig. 2: the relation between CO_2 values (ppm) and measures to ventilate and aerate a classroom during a schoolday (own translation to English of the source: Taskforce Ventilation, 2021)

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3.2 Exposure to radiofrequency radiation from fixed transmitting antennas: more accurate exposure maps to better inform the general public

3.2.1 Introduction

Transmitting antennas, equipped with the latest techonology, make it possible to transmit more and faster data, stimulating the development of interconnectivity, digital services, smart meters, etc. Several studies (e.g. the SmartSantander use-case in Spain (Diez et al, 2017) and the ongoing GOLIAT-5G project in Swisterland) addresses the health impact, by mapping exposure. In turn, we would also like to get a better idea of this in Flanders.

In Belgium, legislation around transmitting antennas is a regional competence. This means that in Flanders, operators of transmitting antennas apply for conformity certificates from the Flemish Department of Environment & Spatial Development before a transmitting antenna is put into service or modified . With these certificates, the Flemish government ensures that the requested condition complies with the standard for exposure to non-ionising radiation from fixed transmitting antennas. Referring to Figure 1, this theme relates to protecting from physical stressors.

In 2010, Flanders drafted its first legislation to limit exposure to electromagnetic fields from transmitting antennas (=radiofrequency or RF radiation). Since mobile telecommunications technology evolved significantly over the past 10 years, an adaptation of the legislation in 2022 was needed. Both times, the choice of the standards were based on international guidelines (ICNIRP), scientific research and on the precautionary principle. To test the impact of the new standards for the 2022 legislation, the Flemish Department of Environment & Spatial Development has simulated the virtual roll out of 5G in 2019 (Gommé et al, 2023). As input data we used the information from the confirmity certificates. These simulations resulted in exposure maps, which do not necessarily correspond to what actually happens in the field: the simulations are based on worst-case exposure. From the perspective of precautionary principle, this is a good approach. However, we still do not know what is happening in the field. By carrying out site measurements, we can get a better picture of what is happening in the field, e.g. peaks or fluctuations in exposure during the day etc. And so, with the sensor measurements we can create more accurate real time exposure maps. The subject of non-ionising radiation can raise concerns in society, and through more accurate and accessible information, we want to reduce concerns.

3.2.2 Spatial analysis of the transmitting antennas and the 5G roll out

Generally speaking, the location of the transmitting antennas follows the population pattern. About half of the sites for transmitting antennas are located in urban (core) area's, and almost one in 4 sites is located on an industrial/business/office parks.[3] In 2019, urban area's made up about 11% of the total area in Flanders and 72% of the population lived there (Pisman et al, 2021). Antennas are more closely spaced together in urban environments, while outside these area's, in more sparsely populated areas, less antennas transmit higher powers. Today, 5G technology is present in about half of the sites for transmitting antennas, but there are spatial differences. When comparing sites with or without 5G technology per type of area, there is a larger share of sites that contain 5G in large urban (core) area's (57%), than outside urban environments (46%).

Figure 3 illustrates these findings. It is a zoom map of the eastern part of Flanders, with Antwerp as the major urban area on the north-west of the map and Mechelen on the south-west (pink urban cores on Figure 3), surrounded by the port of Antwerp industrial zone to the northeast (purple area on Figure 3). The rest of the map consists of smaller urban areas or cores (dark grey areas). The business parks or industrial areas often connect to those cores of (smaller) urban areas, or they are located near major infrastructures, such as highways and canals. Compared to the rest of the map, there is a clear concentration of sites for transmitting antennas in the urban area of Antwerp. In addition, it is noticeable that there is a large mix of sites with both 5G technology (blue dots) and with other technologies (yellow dots), with a slight overweight of sites with 5G technology. In some other, smaller cores, the sites with other technologies are more prevalent, especially in the north-eastern part of the map.

[3] The legislation regulates that certain types of transmitting antennes do not need a comformity certificate, when they operate under a certain Effective Isotropic Radiated Power (EIRP, as a measurement of radiated output power from an ideal isotropic antenna in a single direction) and less than a certain amount of days. However, these antenna's still need to conform to the legal standard to limit exposure to electromagnetic fields.

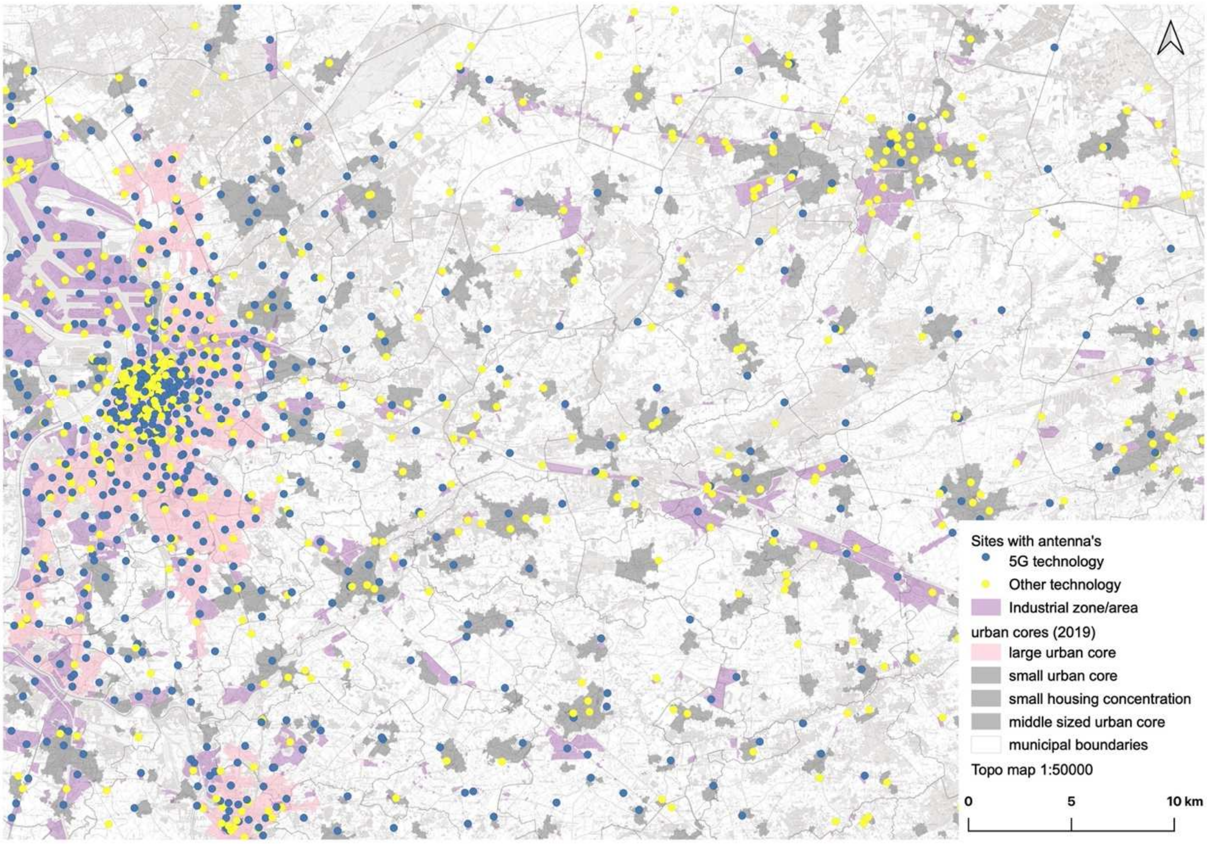

Fig. 3: distribution of sites with 5G and other technologies in Flanders, according to a classification into urban areas/cores and industrial/business areas (own data from conformity certificates)

3.2.3 Research and results

As mentionned in the previous paragraph, the impact of the new legislation, adopting the precautionary principle, was investigated by means of simulations before it came into effect. Now we want to put into practise an exposure monitoring network in Flanders. The ultimate goal of the monitoring network is to map time-dependent exposure to RF radiation based on measurement data collected by sensor boxes and interpolating in zones located between the sensor boxes.

The Flemish Department of Environment & Spatial Development has 27 RF sensor boxes — developed in cooperation with IMEC — that continuously measure exposure to RF radiation from transmitting antennas (Aerts et al, 2022). There is also a data capture platform for receiving the sensor data from the 27 RF sensor boxes. The RF sensor boxes were designed to measure the electric field strength on following four telecom frequency bands: 800 MHz, 900 MHz, 1800 MHz and 3600 MHz.

The research in cooperation with IMEC on the best locations or buildings to place the RF boxes has started in February 2023. An urban environment, specifically the centre of the city of Ghent, was chosen to investigate in this pilot study. The city of Ghent is a suitable location as it reflects well the urban complexity: it is, after Antwerp, the second largest city in Flanders (circa 157 km2, 267.700 inhabitants, 1.695 inhabitants per km2 in 2023). The city centre has quite a dense street pattern, with several markets and squares, which for some parts can be traced back to the Middle Ages. Buildings have different heights, and streets have varying widths (the buildings will attenuate or reflect radiation to some extent). This is in other words a complex environment.

Using a modelled exposure, possible locations for the 27 boxes are proposed, taking into account a variogram analysis to estimate correlation distance and zones where exposure is potentially highest. The plan now is to place the boxes on the facades, roofs or balconies of buildings, mostly with view on the street. To this end, we have enlisted the cooperation of various public or government institutions (university buildings, Flemish government buildings, etc.). The deployment of the sensor boxes will start during the summer and the objective is to collect sensor data during a year, that will be further analysed.

3.2.4 Results

The finality of the study is to feed an interpolation model based on the measurements to come up with an exposure map. This will probably give a different picture than the previous exposure maps based on the conformity certificates. It allows us to take the first steps towards possible monitoring for the whole of Flanders. In addition, it can help us as a government to fulfill our role of monitoring standards[4], and to provide more precise information to citizens.

3.3 Noise exposure getting insight into the causal relationship between noise and health

3.3.1 Introduction: measurements and perception

Noise pollution is categorised in Figure 1 as another physical stressor. International research indicates that noise exposure can cause important health effects such as stress, sleep disturbance and cardiovascular effects (WHO, 2018). If we do not take into account endocrine disruptors, Flemish research cites noise pollution as the second most important factor in calculating DALY (or Disability Adjusted Life Years as a measure of years of life lost due to premature mortality combined with years of healthy life lost due to disability), after particulate matter.

In 2018, the Department of Environment & Spatial Development conducted a five-yearly written environment survey in order to estimate the proportion of inhabitants that are affected by noise, light and odour pollution. It was the fifth survey in a series of identical surveys conducted since 2001. The 2018 survey shows that noise is the main source of annoyance: 29% of Flemish people (or circa 3.299.060 inhabitants) said they felt bothered by noise in and around their homes (categories ranging from moderate (18%) to serious (10%) and extreme noise (2%) annoyance). Traffic and transport noise is the largest source of noise annoyance. More than a third of those with moderate to extreme noise annoyance related this to traffic and transport. People living in urban environments experience the most noise annoyance compared to more rural areas.

Modelled noise pollution maps exist for Flanders:[5] these mainly take into account the main traffic-related sources of noise (e.g. noise from traffic on motorways and other major roads, from high-frequency train connections or from air traffic from airports). However, they remain an estimate of actual noise exposure. To better map effective exposure, the Department of Environment & Spatial Development is collaborating with the University of Ghent, the Provincial Institute of Hygiene and Scivil (Flemish knowledge center for citizen science) on two 24-month projects of Public Procurement Innovation (PPI) with sound sensors, linking on-site outdoor nighttime noise measurements with health effects, sleep disturbance and human perception. The focus is on (1) better capturing personal and dynamic exposure, and relating this to health effects and sleep quality of the participants (PPI I) and (2) mapping environmental noise in Flanders on strategic locations and the appreciation of that environment by rolling out a measurement network of sensors in a citizen science project (PPI II).

3.3.2 Research with sensors: getting insight into the causal relationship between noise during the night and health

Both research projects are currently ongoing. In a first phase, the aim is to search for best-in-class sensors and establish measurement protocols through two pilot studies, so that this can be applied on a larger scale in Flanders in a citizen science project to be launched in a second phase.

The measurement protocols being developed for this is based on literature, but also on ongoing research. This will be done simultaneously with field testing in the form of two pilot studies, with 10 subjects each that live in several spatial environments (urban, suburban and more rural environments). The measurement protocols are designed to correlate noise exposure during the night with health impacts, sleep disturbance and noise pollution. The study allows the analysis of short-term effects on health and sleep and it allows to get insight into the causal relationship between noise and health, without taking confounding factors into account (e.g. air quality). To achieve this, biological response measurements are performed, thanks to an

[4] The sensors have a precision of measurement of more or less 5dB. They can indicate whether a standard has been exceeded. In that case, our enforcement services intervene and can measure with more accurate devices on site.

[5] These maps are based upon a weighted 24-hour annual average sound pressure level, with evening and night levels being relatively more heavily weighted (L_{den})

ECG and actimetry device that the participants carry on their body (heart rate variability, motility,…). As mentioned in the introduction, perception is an important factor when we are dealing with annoyance. Therefore, the project uses a survey, in the form of self-reported noise annoyance and sleep disturbance among the pilot project participants.

In addition, noise at night is measured both inside and outside the home. That simultaneous measurement makes it possible to differentiate between indoor en outdoor noise (and to analyse the difference in impact on sleep), and also to identify the source of the ambient noise. The latter is important knowledge for policy: by knowing the sources, certain measures can be taken if necessary.

3.3.3 Results

Both PPI projects are ongoing. The first one that deals with health effects and sleep quality of the participants, is expected to be completed in December 2023. This project wants to monitor the impact of noise on health. A measurement protocol will be drawn up for later roll-out in a subsequent HBM (Human Biomonitoring) campaign. From this, the effect of noise on health (and quality of life) can then be monitored on a larger scale in Flanders. The second PPI project will end in March 2025. The result will be a proof of concept in order to map noise in Flanders more area-wide (in relation to the existing noise maps), classification of noise sources and their appreciation. A concrete plan of approach will be drawn up, to be used afterwards in a large-scale citizen science project. The data from the citizen science project will serve to create an area-wide map, which can also validate modelled noise maps.

So far, the results of the projects mainly focus on the technical aspects, regarding the the technology used, IT applications, problems encountered during the pilots, etc. This information will be processed in order to establish a concrete measurement protocol for later use.

4 OVERARCHING CONCLUSIONS AND REFLECTIONS ON SENSOR-BASED RESEARCH FOR LIVING IN A HEALTHY ENVIRONMENT

4.1 Reflections concerning spatial planning

This paper first and foremost highlighted the relationship between spatial planning and health by introducing the concept of healthy living and working environments. The physical environment has a major influence – both positive or negative — on our well-being and health. For instance, the beneficial effects of green space on physical and mental health are widely accepted and scientifically researched. Conversely, exposure to chemical pollutants present in air, water, soil, food or in certain products can lead to a broad spectrum of health effects that vary in severity and duration. The same applies to exposure to physical stressors such as noise, radiation, and biological stressors such as bio-effluents, including exhaled CO_2 and moisture but also bio-aerosols such as viruses and bacteria. Introducing more health aspects in spatial planning has several benefits. It takes into account the vulnerability of specific groups, such as the elderly, children and the chronically ill. Research shows that health differences exist between socioeconomic groups, and these differences also manifest themselves spatially (RIVM, 2017).

This paper mainly focused on protection, which is an important task of the government, by starting to measure the exposure of different stressors in the field. The underlying question is what measures help to achieve a healthy living environment. In the case of indoor environmental quality, where we focused on more vulnerable groups such as children and elder people, behaviour plays an important role, and sensitisation of different target groups (inhabitants, staff, architects, building contractors) is an important aspect. The measurements have also directly fed policy at other governmental agencies, e.g. the framework around ventilation and aeration in care centres. With non-ionising radiation from transmitting antennas, it is mainly about the legal standards, which must not be exceeded, and informing people correctly and removing any concerns. Finally, with noise exposure, we are only in the early stages of getting a grip on the state of affairs. These insights can give input to policy measures in the future, such as imposing noise standards in certain environments or specific measures to be included in noise action plans.

Flanders is not the only region dealing with measuring and tackling environmental impact on health. Of some factors, such as RF exposure, we know that other regions and countries are conducting studies to monitor this. Of other factors, we do not yet know about how the results of measurements are implemented in the policies of other countries, e.g. for the case of noise exposure. Presumably, our PPI studies on noise could be relevant as it is conducted within a policy context and rolled out afterwards. In any case, it is interesting to follow up other countries and regions in the future.

Flanders is a densely populated region, and throughout the day everyone is exposed to certain stressors to a greater or lesser extent. Even though exposure partly depends on lifestyle and behaviour, a further exploration of spatial factors in relation to exposure seems interesting. Overall, we know that people living in urban environments are more likely to be exposed to certain environmental stressors, but there may be many differences between urban areas. For example, traffic density, proximity to certain industrial activities (and thus exposure to noise, among other things) play a role and may also occur outside urban areas (or cores) in Flanders. Agricultural activities outside cities, in turn, are a potential source of stressors. These constitute interesting starting points for further spatial research.

4.2 Refections about sensor-based research

Working closely with partners, we were able to develop innovative sensors, which we use in research that supports policy, as well as in policy preparation and standards evaluation. This way of working with sensors has the advantage of being cost-efficient, quick to set up and a step towards an independent and objective measurement network. It also has its challenges because it implies continuous monitoring of the latest technological innovations. The roll-out of different sensors in the field is also a process of learning by doing, that takes some time. It also requires a commitment to building in-house knowledge. Still, it remains worthwhile to enrich our knowledge and models with data in the field. Field measurements allow us to measure many more fluctuations and nuances, and we are closer to people's daily lives.

5 REFERENCES

AERTS, S., VERMEEREN, G., VAN DEN BOSSCHE, M., AMINZADEH, R., VERLOOCK, L., THIELENS, A., LEROUX, P., BERGS, J., BRAEM, B., PHILIPPRON, A., MARTENS, L. & JOSEPH, W.: Lessons Learned from a Distributed RF-EMF Sensor Network. Sensors (Basel), doi: 10.3390/s22051715, 2022.

DIEZ, L., AGÜERO, R. & NUÑOZ, L.: Electromagnetic Field Assessment as a Smart City Service: The SmartSantander Use-Case, in: Sensors 17, no.6:1250. doi: 10.3390/s17061250, 2017.

ELMENHORST, E.-M., GRIEFAHN, B., ROLNY, V. & BASNER, M.: Comparing the Effects of Road, Railway, and Aircraft Noise on Sleep: Exposure–Response Relationships from Pooled Data of Three Laboratory Studies, in: International Journal of Environmental Research and Public Health. International Journal of Environmental Research and Public Health 16, no. 6: 1073. doi: 10.3390/ijerph16061073, 2019.

GOMMÉ, L., VERLAEK, M., DE KEMPENEER, N., GOETHALS, M., VAN HOOF, T., DE MULDER, S. & VAN CAMPENHOUT, K.: Simulations of the virtual roll out of 5G in Flanders with regard to electromagnetic exposure, BioEM 2023, the 2nd Annual Meeting of the BioEM Society, Oxford (United Kingdom), 19-23 June 2023.

GOMMERS, A., VERHAEGEN, K., BAKEN, K. & KOPPEN, G.: Instrumentele analyse van gezondheid in het ruimtelijk beleid, uitgevoerd in opdracht van het Vlaams Planbureau voor Omgeving, 2019.

HIGH HEALTH COUNCIL BELGIUM, Indoor Air Quality in Belgium. Advies nr. 8794. Brussels: HGR, 2017.

LAZAROV, B., ELEN, B., SPRUYT, M, & STRANGER, M.: Long-Term Monitoring of Environmental Pollutants in the Indoor Climate of Various Housing Types, 2019.

PISMAN, A., VANACKER, S., BIESEMAN, H., VANONGEVAL, L., VAN STEERTEGEM, M., POELMANS, L., & VAN DYCK, K. (Eds): Ruimterapport Vlaanderen 2021. Brussels, 2021.

TASKFORCE VENTILATION, Recommendations for practical implementation and monitoring of ventilation and indoor air quality within the framework of COVID-19, 2019. Available at: https://werk.belgie.be/sites/default/files/content/documents/Coronavirus/Implementatieplan_ventilatie.pdf [Accessed August 31, 2023

TEUGHELS, C., VERHEYEN, V., VERVOORT, P., COERTJENS, D., BIJNENS, E., VOS, S., NAWROT, T., DEN HOND, E., SCHOETERS, G. & VAN CAMPENHOUT, K.: From human biomonitoring research to spatial explicit evidence and policy recommendations. Green space exposure and health effects in Flanders (Belgium). 58th Isocarp World Planning Congress, Brussels (Belgium), 3-6 October 2022.

RIJKSINSTITUUT VOOR VOLKSGEZONDHEID EN MILIEU: Gezonde leefomgeving, gezonde mensen. Bilthoven: RIVM, 2017.

WHO: Environmental noise guidelines for the European Region. 2018. Available at: https://www.euro.who.int/en/publications/abstracts/environmental-noise-guidelines-for-the-european-region-2018 [Accessed June 22, 2023]

WHO: Health in all policies: Helsinki statement. Framework for country action. 2014. Available at: https://apps.who.int/iris/bitstream/handle/10665/112636/9789241506908_eng.pdf [Accessed June 21, 2023]