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MASTER THESIS

Bus technology developments over the last sixty years in Switzerland and their impact on driver's health

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Summary

Bus drivers are exposed to many occupational and environmental hazards, generally associated with poor health and increased mortality. In addition, public transport infrastructure has evolved over the past 60 years, including bus design and technology. However, the overall impact of these innovations on drivers' health is unknown. The hypothesis is that technological changes, which aim at improving the vehicles from an energy and comfort point of, have a positive effect on drivers' health. To verify this hypothesis, we use a tool from occupational epidemiology: a job-exposure matrix, where each bus corresponds to a workstation. For this purpose, we identify bus models representative of the evolution of the bus fleet, which are characterized by technical attributes. We then carry out evaluations of physico-chemical risks and biomechanical factors on two first Volvo buses. These evaluations show an evolution in the exposures from one bus to the other, with among other things a decrease in the noise and vibration level, but also a better ergonomic score.

Key words: *physico-chemical risks, measurements, occupational health, ergonomics, evolution, bus*

Résumé

Les conducteurs de bus sont exposés à de nombreux risques professionnels et environnementaux, généralement associés à une mauvaise santé et à une mortalité accrue. En outre, l'infrastructure des transports publics a évolué au cours des 60 dernières années, notamment la conception et les technologies des bus. Cependant, l'impact global de ces innovations sur la santé des conducteurs est inconnu. Nous émettons l'hypothèse que l'évolution technologique, qui vise à améliorer les véhicules du point de vue de l'énergie et du confort, a un effet positif sur la santé des conducteurs. Afin de la vérifier, nous utilisons un outil issu de l'épidémiologie professionnelle : une matrice poste-expositions, où chaque bus correspond à un poste de travail. Pour cela, nous identifions des modèles de bus représentatifs de l'évolution de la flotte qui sont caractérisés par des attributs techniques. Nous effectuons ensuite des évaluations des risques physico-chimiques et de facteurs biomécaniques sur deux premiers bus Volvo. Ces évaluations démontrent une évolution dans les expositions d'un bus à l'autre, avec entre autres une diminution du niveau de bruit et des vibrations, mais également un meilleur score ergonomique.

Mots clés : *risques physico-chimiques, mesures, santé au travail, ergonomie, évolution, bus*

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I) Nomenclature

L	[cd/m2]	Luminance
C	[-]	Contrast
R_L	[-]	Ratio of luminance
V	[m^3]	Volume
C(t)	[ppm]	CO_2 concentration
Q	[m^3/h]	Air flux
L_{eq}	[dB(A)]	Equivalent noise level
L_{peak}	[dB(C)]	Peak level
a_w	[m/s^2]	Weighted acceleration
A(8)	[m/s^2]	Daily exposure to vibrations
t	[h]	Time of exposure

II) Abbreviations

BEM	Bus Exposure Matrix
PTC	Public Transport Company
AER	Air Exchange Rate
ASHRAE	American Society of Heating, Refrigerating and Air-Conditioning Engineers
EF	Electric Fields
PM_{10}	Particulate Matter with a diameter smaller than 10 micrometers
SEAT	Seat Effective Amplitude Transmissibility

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1 Introduction

1.1 Context

Since the 1950s, numerous studies have been conducted on the health of bus drivers. These studies have highlighted the numerous occupational and environmental risks to which these workers are exposed [1-4] and have associated them with increased morbidity and mortality [5-9]. Currently, there are only three cohorts in the world studying the health of bus drivers, in Italy [10], Denmark [7] and Taiwan [8]. Unfortunately, they have little information on working conditions, which have changed dramatically over the last 60 years. This mainly concerns the design of buses and the behavior of public transport users [11, 12]. However, the overall impact of these technological developments on the health of drivers remains unknown. Indeed most toxicological and epidemiological studies focus on occupational hazards and their effects without considering the evolution of vehicles.

To fill this gap, a Job-Exposure Matrix (JEM), a tool used in occupational epidemiology, will be created. It is a multidimensional table providing, for each workstation in a company, the level of exposure corresponding to the hazards related to this workstation [13, 14]. The driver's workstation being buses, we will create a Bus Exposure Matrix (BEM) by analogy with the JEM. In this first part of the project, we focus on the technological aspects; we do not consider the psychosocial aspects. They will be evaluated at a later stage.

1.2 Objectives

The main objective of this master thesis project is to begin the construction of the BEM. To do so, three sub-objectives must be achieved. The first is to understand the issues and determine which exposures are to include in the BEM. The second is to make an inventory of the buses present in Switzerland since the 1960s. This leads to the creation of the typology of the Swiss buses. The last sub-objective is to carry out measurement campaigns to determine the different exposures related to the work of a bus driver.

1.3 Structure of the project

This project is structured in four different phases, as followed:

I. The literature revue: a necessary step to learn what has already been done, but also to understand the stakes of the project and determine the measures we want to do.
II. The creation of the inventory and the typology of the Swiss bus fleet since the 1960s.
III. The measurements campaign and the analysis of the data to extract the exposure to the different chosen pollutants and ergonomic parameters.
IV. The construction of the BEM

2 Literature review

We search among various international databases such as Pubmed, Elsevier and ScienceDirect to find studies highlighting the typical health problems of bus, cab, and truck drivers. The scoping review approach is adopted. First, we select reviews to get an overall picture. Then, we choose the issues that seemed the most important to conduct a targeted literature review and to investigate these topics in greater depth.

Nearly 20 health issues are identified. They include cardiovascular diseases[4, 8, 15, 16], lung [5, 7, 10, 15], breast [17, 18] and bladder cancers [7, 18], musculoskeletal diseases [2, 3, 19-22], sleep disorders [23-27], gastrointestinal problems[10, 19, 22, 28], mental disorder [18, 28] and fertility and productivity disorders [18, 29] . They are related to the nuisances presented in the paragraph below.

We can separate the nuisances into several categories. The first ones are physicochemical nuisances including particles [10, 15, 17], other diesel exhaust [7, 10, 18] and ozone (O_3) [30]. The second category corresponds to physical nuisances including noise [22, 31, 32], temperature [29, 33, 34] and vibrations [2, 19, 22, 28]. The third category includes psychosocial nuisances like stress at work and working hours [18, 19, 27, 28], and nuisances related to the ergonomics of the workstation, which correspond to repeated movements and the sitting position [18, 19, 21]. Other nuisances, such as electromagnetic fields, are also considered, despite the absence of evidence of effect in the driver population [35, 36]. The Annex 1: Mind map of the health issues of bus drivers and their causes synthesizes all the findings on the health issues characteristics of the bus driver population and their probable causes.

Based on these findings, we choose to characterize the exposures to illuminance, electromagnetic fields, PM_{10}, noise, vibrations, and temperature of the seat. We include in our study the visual contrast and the ergonomic parameters. We want to determine if drivers have the possibility to have an ergonomic workstation.

The Table 1 links the chosen exposures and parameters to measure and the elements of the bus that might influence them. Those elements are partly used to characterize the different bus models.

Table 1: Parameters to measure and their factors of influence

Parameters	Factors of influence
Light (illuminance)	Indoor light, screens, outdoor environment
Visual contrast based on luminance	Indoor light, screens, dashboard elements, outdoor environment
Air Exchange Rate (AER)	Ventilation, windows, number of passengers, outdoor pollution
Noise	Type, position and soundproofing of the engine, windows, number of passengers, on-board equipment, etc.
Particulate Matter PM_{10}	Ventilation, filters, windows, outdoor pollution
Electromagnetic fields	Engine, on-board equipment, mobile phone, outdoor environment, car body
Vibrations	Type and position of the engine, suspensions, seat, road conditions
Seat temperature	Type of seat, used materials, integrated heater
Ergonomic parameters	Seat, workstation, steering wheel, dashboard, pedals, heater, air conditioning

We also carry out a literature review on the measurement methods and on the limit values of the pollutants of interest.

3 Methods

3.1 Typology of Swiss buses

A first research is made to know all the public transport companies (PTC) present in Switzerland, which use buses and trolleybuses. Then, we investigate each website of each PTC to create a database of the buses and trolleybuses present in Switzerland. This database is then completed with the help of the PTCs willing to collaborate, associations of bus and trolleybus lovers such as the association RétroBus Léman (later named only RétroBus) [37] and other websites maintained by these various associations. The criteria corresponding to the columns of the database are established with the help of the Union Public Transport (in French: *Union des Transports Publics*

UTP) bus branch [38] and the Union of Transportation Employees bus branch, also called SEV [39]. These criteria are completed with elements that might influence the physicochemical hazards and ergonomic parameters of the driver's cabin such as the engine type (cf. Table 1).

Following the construction of the database, we can create a typology of the Swiss buses based on the following criteria:

1. Size
2. Type of motorization
3. Gearbox type
4. Engine position
5. Driving assistance
6. Driving aids

Based on the typology, representative models are chosen to show the technological evolution as well as the different types of buses. We also take into account the availability of buses and their abundance on the Swiss roads between 1960 and 2021.

3.2 Measurements

Once the first phases are completed, the choice of measurements is made to characterize the nuisances caused by buses. These measurements are divided into two distinct parts. The first one is the static measurements corresponding to the analysis of the light, the visual contrast, ergonomic parameters of the driver's cabin, the air exchange rate, and the electromagnetic field at low frequencies (5 Hz to 100 kHz). The second part correspond to the measurements made during simulated trips, it includes the measures of the electric field (100 kHz to 7 GHz), the noise, the vibrations, the particulate matter (PM_{10}) and the seat temperature.

For the simulation, there is a distinction between the urban and the regional types of bus lines. The urban type of lines corresponds to city lines with frequent stops, every 1 to 4 minutes. The regional type of lines consists of the intercity lines with longer driving periods between stops. In this project, the urban simulation is a tour with 21 stops of about 12 kilometers around Moudon, and the regional simulation is a trip with 10 stops of about 12 km between Moudon and Servion. The regional simulation is done two times (round-trip) to ensure enough time for the temperature measurement without the seat pad used for the vibrations measurements. Figure 1 shows the course of the measurement campaigns with indication of the chosen parameters to measure and an estimation of the duration of the different parts.

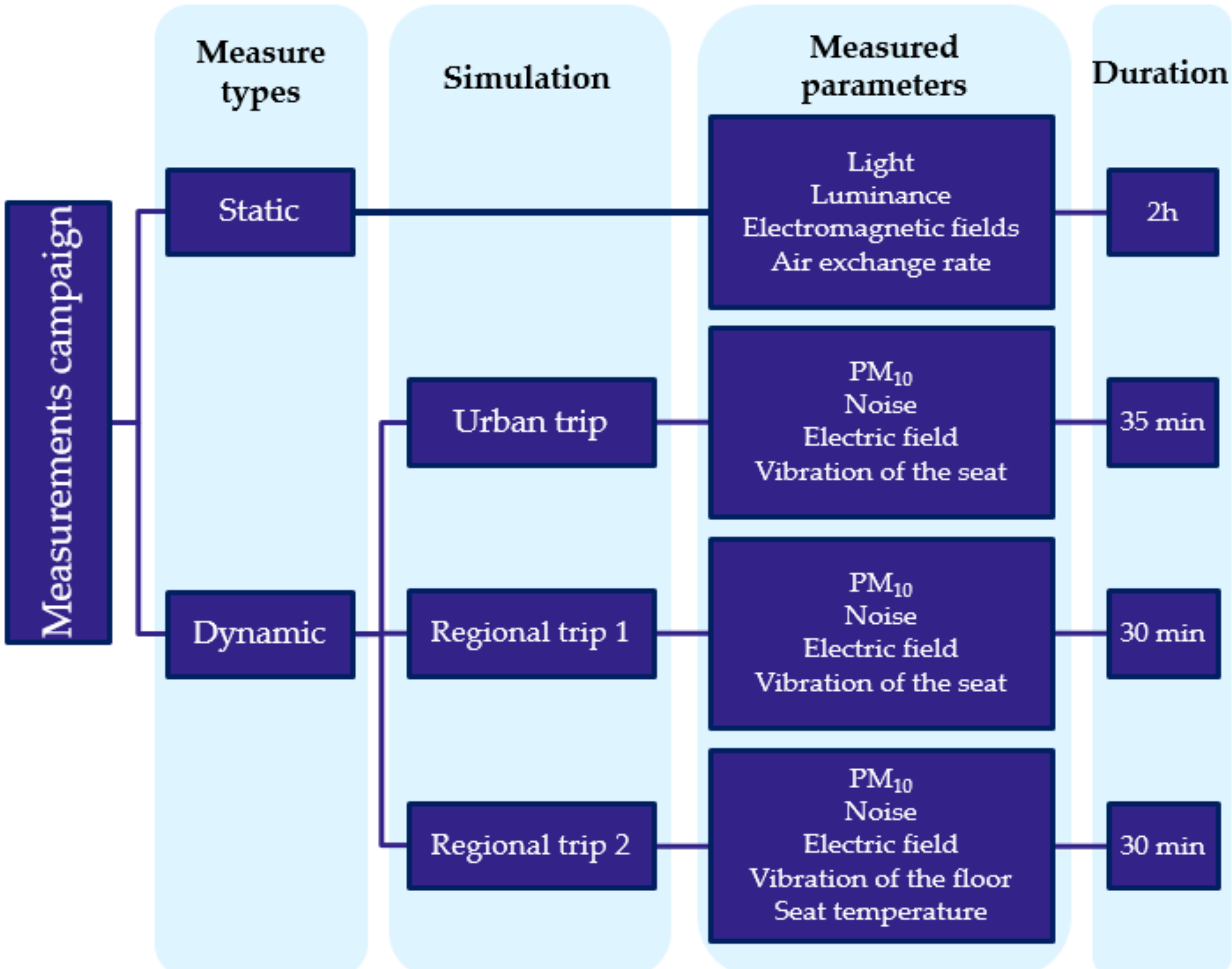


Figure 1: The course of measurements campaigns with an estimation of the duration of each measurements phase

3.2.1 Light

We measure the illumination using the Mavo Spot 2 USB (Gossen, Germany) and its reflection standard [40]. As the light depend on the external surrounding, it is used to assure similar conditions for the measurement of the luminance as the illumination vary along the day. It is therefore not possible to judge the light repartition for each bus as it is strongly dependent on the road illumination and daily weather. Measures are taken in the middle of the steering wheel, and on the left and right parts of the dashboard.

3.2.2 Visual contrast based on luminance

The visual contrast can be defined as the distinction between the appearance of two parts of the visual field seen simultaneously or successively. It is computed based on the luminance (L) of the objects, meaning on the brightness of the considered surface measured in candela per meter square (cd/m^2). The contrast (C) is computed using the equation (1) [41]. This indicator is used to determine if the element is sufficiently visible compare to the background.

$$C = \frac{L_{element} - L_{background}}{L_{background}} \quad (1)$$

Another definition of contrast is the ratio of luminance (R_L), this computed with the relation 2. We use it to verify that there is no blinding effect between the elements of interest and the background.

$$R_L = \frac{L_{element}}{L_{Background}} \quad (2)$$

We measure the luminance of the pictograms, warning signals and other elements of the dashboard of the bus with the luminancemeter Mavo Spot 2 (Gossen, Germany) [40].

The luminance of a small element in the working area of the visual field should not excess 2 000 cd/m^2 to avoid disturbing glare [41]. Plus, the contrast should be of at least 0.7 to ensure a good visibility [42]. However, the ratio between the element of interest and the working surface, in our case the dashboard, should be between 3:1 and 40:1, a higher ratio can lead to blinding effect[43].

We convert the contrast and ratio to a score and include it in the score of the ergonomic design of the bus driver's cabin. It corresponds to 2 points if the contrast is sufficient and the ratio falls into the range mentioned above, to 1 point when one or the other parameter is not respected for more than two elements and 0 when none of them are reached for more than two elements.

3.2.3 Ergonomic parameters of the driver's cabin

In this project, we are evaluating the design of the driver's station to determine whether drivers have the possibility of having an ergonomic workstation. The different ergonomics parameters of the driving position are based on standards, guides and prevention articles of occupations related to the sitting position and vehicle driving positions [19, 44, 45].

The elements to be studied are first the seat, evaluated according to 14 criteria divided between its dimensions (height of the backrest, length of the seat, etc.), the possible adjustments (inclination of the seat, inclination of the backrest, etc.), the lumbar support and its adjustments, the type of suspension (spring, air, etc.) and its adjustment, but also the ease of the adjustments. The second element observed is the steering wheel characterized by its diameter and its adjustments (height, inclination, front-rear). Then there are the pedals, where we are interested in their angle and whether drivers of any stature can reach them. The fourth element is the dashboard where we evaluate the uniformity of design by indicator category, ease of reading, visibility, and the accessibility of the most used controls such as door opening, gearbox and safety brake. The last element is the working space where we evaluate its accessibility (height and width of the door), its place (height of the cabin, legroom), the efficiency and the adjustments of the heating and air conditioning system, the accessibility of other equipment used less frequently by the driver such as the radio, ventilation, on-board sales of travel tickets, or the microphone. Of the 34 biomechanical criteria chosen, 24 are measurable and independent of the driver, 3 are checked with the help of the driver who will perform specific tasks such as reaching the radio or the cash register for on-board sales. The remaining 6 criteria are subjective, they are evaluated with the help of the driver by using photos taken from the driver's seat to compare the vehicles between them in case of doubt. All results are in the form of a yes/no questionnaire except for the number of adjustable functions and the type of seat suspension. The questionnaire is presented in Annex 2.

We convert the result of the questionnaire into three scores. Each item with a "yes" scores 1 point, and a "no" corresponds to 0 point. All the items are added together to give the global score. There is a score for the biomechanical parameters, corresponding to all categories except the dashboard one, however the reachability of the most used elements is included into this score. Furthermore, the two points on heating and cooling system are not considered in the biomechanics score. The third score corresponds to the visual ergonomic and integrate the dashboard category minus the reachability and the visual contrast explained in section 3.2.2. The final note is then computed using the following relation:

$$Final\ score = \frac{Score\ obtained}{Maximal\ possible\ score} * 100\,, \tag{3}$$

with a maximal possible score corresponding to the sum of all the possible points for each score

The maximal possible global score is 32 and 34 when the headrest is disjointed of the backrest. The maximal visual score is 6 and the maximal biomechanical score is 24 and 26 with disjointed headrest. The maximum rating of each score is 100. The higher the score, the more ergonomic is the driver workplace.

3.2.4 Air exchange rate

The air exchange rate (AER) computation is based on the CO_2 tracer gas concentration decay method [46]. The first thing to do is to prepare the bus, meaning closing all the windows, setting the ventilation to high (maximum possible) and opening all the ventilation outlet. The air injected must be sucked from outside. We also dispose two fans at different spots to assure well mix air conditions. We use a Testo 435-2 (Testo AG, Germany) [47] device to measure CO_2 concentration placed near the middle of the bus with a visible screen from the outside. Then, we release the CO_2 coming from a soda stream refill cylinder until we reach a concentration of at least 2000 ppm. We then close the door, which correspond to the beginning of the measures. We stop the recording when the concentration of CO_2 is below 1000 ppm.

The computation of the AER using a tracer gas decay is based on the mass balance equation of a tracer gas (Equation 4). To find the AER, we solve the Equation 5 [46].

$$V\frac{dC(t)}{dt} + QC(t) = 0 \text{ , with V the volume, Q the air flux, and C the } CO_2 \text{ concentration} \quad (4)$$

$$\frac{C(t)}{C(t_0)} = \exp\left(-\frac{Q}{V}t\right), \quad \text{with } \frac{Q}{V} = \text{AER} \quad (5)$$

There is no standard for the AER of public transports. However, they exist for different types of location such as home or restaurant (cf Table 2). As a bus driver needs to be able to focus and a bus can be densely occupied, the AER should be similar to the one of a school at least, meaning 5 to 6 air changes per hour.

Table 2: Suggested air exchange rate for different location types, data coming from the ASHRAE standard

Suggested air change per hours	Location type
0.35 - 1	Home
2 - 3	Offices
2 – 3	Retail shops
5 – 6	School
6 – 8	Restaurant

The American Society of Heating, Refrigerating and Air-Conditioning Engineers (ASHRAE) standard gives specifications for ventilation in public transportation. It is required to have 8 liter per second per person of outdoor air for a bus with a maximal occupancy of 150 persons for 100 m^2 [48]. Based on the solution of equation 4, it is possible to compute the possible occupancy based on the ventilation flux. The new equation becomes:

$$Possible\ occupancy = \frac{Q\left[{}^{l}/_{s}\right]}{8\left[{}^{l}/_{s * person}\right]} \quad (6)$$

This number can be compared to the maximal occupancy of the bus.

3.2.5 Electromagnetic fields

We use the device PMM 8053 and the probes EHP-50A and EP745 (PMM S.r.l, Italy) [49] to measure the electromagnetic fields.

The EHP-50A probe allows the simultaneous measure of the electric and magnetic fields for the frequencies between 5 to 100 kilohertz (kHz). This probe is used for the static measurements as it is mounted on a tripod and nobody must be in a radius of 5 meters. The exposition is recorded for 10 minutes and then, the average is taken as the dose.

The EP745 probe is used to measure the electric fields for the frequencies between 100 kHz and 7 GHz. We position the probe near the driver, but at least 20 centimeters away to have the minimal shielding effect [36]. The exposition to electric fields is recorded continuously during the three simulations. The dose is computed as the average of the exposition for each type of simulation. To compare the value with the maximal exposition according to *The Ordinance relating to Protection from Non-Ionizing Radiation*, we take the highest mean over 6 minutes for each type of simulation [50].

The limit values for electric fields are summarized in the Table 3. For the magnetic field at low frequencies (3 – 100 kHZ), the limit value is 6.25 micro-Tesla (µT)

Table 3: Limit values for the electric fields according to *The Ordinance relating to Protection from Non-Ionizing Radiation [50].* The frequency f is taken in MHz.

Frequency	3-100 [kHz]	0.1 -1 [MHz]	1-10 [MHz]	10-400 [MHz]	400-2 000 [MHz]	2 -10 [GHz]
Strength of electric fields [V/m]	87	87	$87/f^{0.5}$	28	$1.375*f^{0.5}$	61

3.2.6 Particulate matter: PM_{10}

We record the PM_{10} concentration using the device pDR-1500 (Thermo Fisher Scientific, USA) [51]. We place the device above or at proximity of the driver. The dose for each type of simulation is computed as the average for each type of trip. The data is compared to the daily average for the region of Moudon taken in the web site of the Federal Office of Environment [52]. To have a rough estimation of the efficiency of the filter, if existing, we compute the ratio between the measured average and the daily average. A ratio below 1 indicates that the filter retains part of the particles, however, a ratio higher than 1 means an accumulation of particles inside the bus.

The yearly average for PM_{10} is 20 micrograms per cubic meter (µg/m^3), and the daily limit value is 50 (µg/m^3), which we can exceed only three times a year. Those values come from *The Ordinance of the 16th of December 1985 on the Air Protection* [53].

3.2.7 Noise

We record the noise exposure of the simulated trip using two different devices from the same manufacturer: the dosimeters 4448 [54] and 4445 [55] (Bruel & Kjaer, Danemark). We place a first dosimeter on the shoulder of the bus driver in accordance to the guide [54]. However, a second dosimeter is positioned above the driver as a backup; it records the data continuously during the whole simulation period. Both devices allow the measurement of the continuous equivalent level (L_{eq}) in decibel A (dB(A)) and the peak level (L_{peak}) in decibel C (dB(C)).

The dose of equivalent noise is the average of L_{eq} over the duration of each type of simulation. It is computed using the logarithmic average (Equation 7). The same equation is used to average the peak level.

$$L_{eq} = 10\log_{10}\left(\frac{\sum_{i=1}^{N} 10^{L_i/10}}{N}\right), with\ L_i\ the\ acoustic\ level\ and\ N\ the\ number\ of\ sample \tag{7}$$

The limit value for the continuous equivalent level is 85 dB(A) and for the peak level it is 135 dB(C), according to Swiss *Ordinance on the Labor act* and publishes in a SUVA document [56].

3.2.8 Vibrations

The vibrations are measured as accelerations in meter per square second in the three-direction x, y and z. To record the vibration data, we use the device NOR136 (Norsonic, Norway) [57]. For the vibration of the seat during the first two simulations, we place the triaxial seat pad accelerometer NOR1286 on the seat, with the y–axis in the same direction as the road. In addition, for the vibrations of the floor during the third simulation, we place the triaxial accelerometer Nor1288 on the floor just below the seat, with the y-axis in the same direction as the probe placed on the seat [58].

To compute the daily exposure, we first need to compute the root mean square (r.m.s) for the acceleration (a_w) in the three directions x, y, and z (Equation 8).

$$a_w = \left(\sum_{i=1}^{N} \frac{a_{w,i}^2}{N}\right)^{1/2}, with\ N\ the\ number\ of\ samples \tag{8}$$

Then, we can find the daily exposure using Equations 9 to 11.

$$A_x(8) = 1.4 * a_{w,x}\sqrt{\frac{t_{exposure}}{t_{tot}}} \tag{9}$$

$$A_y(8) = 1.4 * a_{w,y}\sqrt{\frac{t_{exposure}}{t_{tot}}} \tag{10}$$

$$A_z(8) = a_{w,z}\sqrt{\frac{t_{exposure}}{t_{tot}}} \tag{11}$$

With $t_{exposure}$ the time exposed to vibration and t_{tot} the total work time, which is taken as 8 hours.

We choose a $t_{exposure}$ of 7.5 hours, as the driver is not all the time in the bus. The value of A(8) decreases when choosing lower $t_{exposure}$. We pick the highest value of $A_x(8)$, $A_y(8)$ and $A_z(8)$ as the daily vibrations exposure and as the dose of vibrations [45].

To assess the efficiency of the seat isolation, we compute the Seat Effective Amplitude Transmissibility (SEAT) values in the three directions using the equation 12.

$$SEAT_{r.m.s}\% = \frac{Vibration_{seat}}{Vibration_{floor}} \times 100\%\ , with\ vibration\ taken\ as\ r.m.s \tag{12}$$

A SEAT value below 100% means an attenuation of the floor vibration by the seat, in contrary, a value higher than 100% indicates that the seat intensifies the vibration from the floor [59].

For vibrations, the daily exposure action value is 0.5 m/s², above this level, employers must take measures to control exposure, and the daily exposure limit value is 1.15 m/s². Those values are extracted from the Swiss *Ordinance on the Labor act* and publishes in a SUVA document [56].

3.2.9 Seat temperature

We measure the seat temperature in Celsius degree (°C) with a thermal camera Flir C5 (Teledyne FLIR, USA) [60]. A picture is taken at the end of the third simulation and the drive to the bus depot. This corresponds to a 30 minutes driving period without the NOR1286 seat pad on the seat. A second picture is taken after 2 minutes to access whether the seat cushion cools down rapidly. A temperature higher than 39 °C is considered as potentially harmful for male fertility [29].

To have an indication of the ambient temperature, we measure it with the device pDR-1500 (Thermo Fisher Scientific, USA)[51]. The data is then plotted and an average is computed.

4 Results

4.1 Typology of Swiss buses

We have identified 75 PTC spread throughout Switzerland. This includes subcontractors and some companies that have ceased to exist due to a merger.

Each bus model is characterized by 52 attributes that correspond to the brand, the type of vehicle, the years of service, and technical characteristics such as dimensions, engine, driving assistance, soundproofing, but also elements that depended on the choice of the PTC such as driving aids like adaptive cruise. The complete list of characteristics is presented in Annex 3: Complete list of the attributes characterizing a bus model

We have found 315 different bus models that have been in service between the years 1940 and 2021. This corresponds to 62 trolleybus models, 228 thermal bus models (diesel or gas), 13 hybrid bus models and 10 electric bus models. These models are divided into 31 different brands, including Mercedes-Benz, MAN, Volvo, FBW, Saurer and Hess, to name only the most represented brands in Switzerland.

We can also sort the buses according to their size. There are 6 categories: solo (≥11 m), midi (between 8 and 11 m), mini (≤ 8m), articulated, bi-articulated and double-decker bus. The typology is made by separating trolley buses from other vehicles and separating articulated buses from non-articulated buses. Minibuses are treated separately.

The typology is based on 6 criteria: the type of bus (solo, midi, mini, articulated, etc.), the type of motorization (thermal, hybrid, electric), the type of gearbox (mechanical, semi-automatic, automatic, without), the position of the engine (front, center, rear), the type of driving assistance (absent, hydraulic, electro-hydraulic), and other driving aids such as the adaptive cruise control (yes, no). A temporal typology for midi and solo bus is shown in Annex 4: Temporal evolution of buses. It highlights the different types of buses and informs on the temporality.

For the representative models that are used to make the measurements of exposure to the different nuisances, we are only interested in the solo and midi buses. These two types are similar enough to be treated together and to represent most of the models present in Switzerland. Moreover, most of the articulated models are a variation of the solo models and therefore have an almost identical workstation. For the solo-midi category, we have found 21 bus types. We have reduced the choice to 12 representative models considering the period of service and the abundance of these types of buses in Switzerland. The non-exhaustive list of representative buses is represented in Table 4. The type of bus will not change but the exact model might change due to availability. Buses that are no longer in circulation can be borrowed from RétroBus. For the other, we will work with PTC that are willing to participate.

Table 4: Choice of the representative models. M=mechanical, S=Semi-automatic, A=Automatic, A/N= Automatic or none, H=hydraulic, H-E= Electrohydraulic

Bus type	Gear box	Engine position	Assis tance	Euro norm	Driving aids	Brand	Model	Service year
Thermal	**M**	**Center**	**H**	**-**	**No**	**FBW**	**B71U**	**1955-1980s**
Thermal	**M**	**Front**	**None**	**-**	**No**	**Saurer**	**SV 2 CK**	**1958-1980s**
Thermal	**S**	**Center**	**H**	**-**	**No**	**Volvo**	**B58**	**1972-2002**
Thermal	**A**	**Front**	**H**	**-**	**No**	**FBW**	**91 U**	**1975-2004**
Thermal	**A**	**Center**	**H**	**0-1**	**No**	**Volvo**	**B10M**	**1983-2015**
Thermal	**A**	**Center**	**H**	**2-3**	**No**	**Van Hool**	**A308**	**1997-2019**
Thermal	**A**	**Rear**	**H**	**2-5**	**No**	**Mercedes-Benz**	**Citaro**	**1998-2020s**
Thermal	**R**	**Rear**	**H**	**5**	**No**	**Setra**	**S 411 HD**	**2011-**
Hybrid	**A**	**Rear**	**H**	**5**	**Yes**	**MAN**	**Lion's City**	**2012-**
Thermal	**A**	**Rear**	**H**	**6**	**Yes**	**MAN**	**Lion's City**	**2017-**
Hybrid	**A**	**Rear**	**E-H**	**6**	**Yes**	**Mercedes-Benz**	**Citaro Hybrid**	**2018-**
Electric	**A/N**	**Rear**	**E-H**	**6**	**Yes**	**Mercedes-Benz**	**eCitaro**	**2019-**

4.2 Measurements

The static measurements are done in the RétroBus warehouse in Moudon, with spotlights to illuminate the driver's cabin and guarantee similar conditions for each bus.

The urban simulation is a 12 kilometers round tour in Moudon and its surroundings. The map of the tour with the stop positions is presented in Annex 5: Map of the urban simulation It is a concrete road with a speed limit of 50 km/h in the city and 80 km/h in its surroundings.

The regional simulations correspond to a 12 kilometers trip, back and forth, between Moudon and Servion. The Annex 6: Map of the regional simulations shows the map of the trips with indication of the bus stop positions. It is a concrete road with speed limit between 50 km/h in town and 100 km/h in semi-highway.

The buses used for the measurements are a Volvo B58 and a Volvo B10M. They currently belong to the association RétroBus. For the simulation, they are driven by two RétroBus members, which are also professional drivers. One driver does the urban simulation and the other the regional simulations.

The Volvo B58 (Figure 2) is a semi-automatic solo-bus first registered in 1970 in Winterthur. It was later used by the civil protection. Its end of service was around 1990. RétroBus collected it only during the 2000s.
The motor is positioned in the middle but slightly in the front of the bus with no soundproofing. Its suspensions are air over leaf spring. No major repairs were done, only the engine, the gearbox and the bodywork were overhauled. This model was spread in Switzerland until the 1990s.

Figure 2: Volvo B58

Figure 3: Volvo B10M (*bus-bild.de)*

The Volvo B10M (Figure 3) is an automatic solo-bus first registered in 1986 in Schaffhouse. It was later transformed into a driving school bus. To do so, they removed the driver's door and installed a chair for the instructor. RétroBus took this away. Its end of service was in 2002, RétroBus then collected it in 2021. The motor is positioned in the middle and does not have soundproofing. It has only air spring suspension. No major repair was done, there was only a complete overhaul. This model was spread in Switzerland until the 2000s.

4.2.1 Light

The illumination value in the middle of the steering wheel is 37.2 [lx] and in the middle of the dashboard is 22.7 [lx] for the Volvo B58. For the Volvo B10M, they are 41 [lx] and 50.8 [lx] for respectively the steering wheel and the dashboard. The difference of layout of dashboard explains these differences in illumination as the same spotlight is used in both cases.

4.2.2 Visual contrast

The warning signals of the Volvo B58 are blinking. The different indicators as the warning signals and the different arrows are backlighted. We measure the luminance of 12 elements, which include the brake warning and high beam signal. The chosen elements are represented in the Figure 4.

Figure 4: Luminance measurements of dashboard elements of Volvo B58. 1) Brake, 2) Handbrake, 3) Blinker, 4) High beam, 5) Front door, 6) TELMA, 7) Battery, 8) Water level, 9) Arrow, 10) Speed arrow, 11) Background 1, 12) Background with glass on top. The alert buttons are blinking type of button.

The contrast C and the ratio R_L are computed between the different elements of the dashboard. We consider only the juxtaposed elements. The results are shown in Table 5. On the 10 computed ratios, only 3 are conform to the acceptable range, meaning that the others might have a blinding effect for the driver. Though, all the contrasts are high enough to be distinguished easily. This equals to a score of 1 in the ergonomics study of the driver’s cabin.

Table 5: Contrast of the Volvo B58 dashboard elements. In *dark red* are the values falling out of the range of luminance ratio (3 – 40)

Elements	Contrast (C)	Ratio (R_L)
1 & 11	108.29	*68.7*
2 & 11	108.29	*68.7*
3 & 11	87.30	*55.5*
4 & 11	35.70	23.1
5 & 11	76.72	*48.9*
6 & 11	256.30	*161.8*
7 & 11	1926.00	*1211.9*
8 & 11	13.49	9.1
9 & 12	3.40	*0.6*
10 & 12	2.32	4.4

On the Volvo B10M, a button allows lighting up all the warning signals to control their proper functioning. It also allows us to easily measure the luminance of the thirteen chosen backlighted elements, which are shown in Figure 5.

Figure 5: Luminance measurements of dashboard elements of Volvo B10M. 1) Heated rearview mirror, 2) Blinker, 3) High beam, 4) Motor temperature, 5) Doors, 6) Engine oil level, 7) Water level, 8) Little red alarm, 9) Neutral position button, 10) Door button, 11) Speed arrow, 12) Little alert, 13) Background 1, 14) Background with glass on top

The Table 6 summarizes the contrast C and ratio R_L of juxtaposed elements of the dashboard. On the 17 contrasts computed, only 1 is too low (below 0.7), the others are high enough to be distinguished. However, the ratio R_L is too low in 3 cases and too high in 4, meaning a possible blinding effect. It corresponds to a score of 1 for the ergonomic analysis.

Table 6: Contrast of the Volvo B10M dashboard elements. In *dark red* are the values falling out of the range of luminance ratio (3 – 40) or below the contrast of 0.7

Elements	Contrast (C)	Ratio (R_L)
1 & 13	12.70	13.7
2 & 13	27.99	29.0
3 & 13	4.20	5.2
4 & 13	19.69	20.7
5 & 13	32.78	33.8
6 & 13	27.99	*77.3*
7 & 13	76.30	*186.2*
2 & 3	4.58	4.1
Average orange & average red	3.84	4.8
Average orange & average green	5.17	6.2
Average orange & average blue	24.36	25.4
Average green & average red	*0.28*	*1.3*
8 & 14	71.48	*72.5*
9 & 13	12.58	13.6
10 & 13	79.30	*80.3*
11 & 14	1.56	*2.6*
12 & 13	0.71	*1.7*

4.2.3 Ergonomic parameter of the driver's workplace

The Figure 6 shows the driving cabin of the Volvo B58.

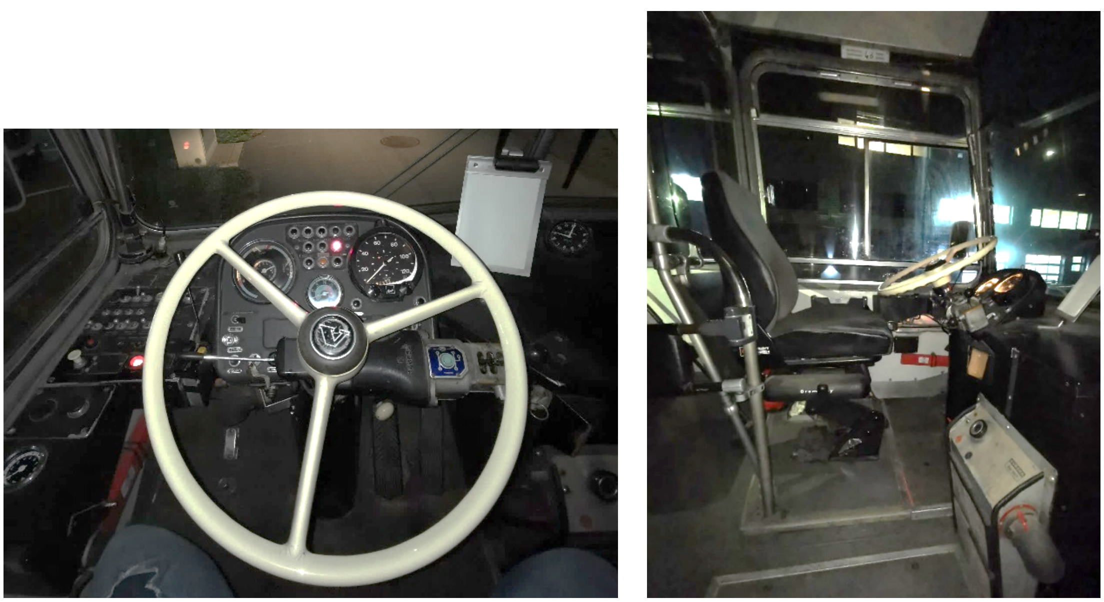


Figure 6: Dashboard, steering wheel (left) and workstation (right) of the bus Volvo B58

The Volvo B58 has a spring suspended seat with 7 settings, the model is Grammer Bremshey. Despite all this setting, it checks only 4 on the 13 ergonomic criteria analyzed for the seat. The good points are the back-and-forth adjustment, the seat tilt adjustment, the lumbar support, and the height of the backrest. Concerning the steering wheel and the dashboard, the criteria met are the size of the steering wheel, the uniform design and ease to read. The pedals have a good range of angles and are reachable by small drivers. The workspace is too small; the only good point is the efficiency of the heater. On 32 criteria, only 11 are respected, giving a global score of 34.4, this considers the contrast analysis done in the section 4.2.2. The different scores for this bus are presented in Table 7.

The Figure 7 shows the driver's cabin of the Volvo B10M. The fan and spot are not part of the bus but are used for the measurements.

Figure 7: Dashboard, steering wheel (left) and workstation (right) of the bus Volvo B10M

The Volvo B10M has the same seat model as the Volvo B58, the difference is the age of the seat. They have the same default except for the ease of the controls for the adjustments which is better for the Volvo B10M. Furthermore, the height of the backrest is lower for the Volvo B10M and thus does not comply with the chosen criterion. The points concerning the steering wheel are not respected except for its diameter. The only positive point for the pedals is that a small driver can easily reach them. The dashboard checks all the yes cases in the questionnaire. One more time, the working space is too small, and only the efficiency and adaptability of the heater complies with the criteria of the driver's cabin. In total, the Volvo B10M meets only 13 criteria on the 32 analyzed, corresponding to a score of 40.6, it includes the score of the contrast analysis done in section 4.2.2. The different scores for this bus are presented in the table below.

Table 7: Summary of the ergonomic score for both buses. The scores include the results of the contrast and ratio presented above. The maximum possible score is 100 for each category.

	Volvo B58	Volvo B10M
Global score	34.4	40.6
Visual score	50	83.3
Biomechanical score	26.9	26.9

The biomechanical scores are the same for both buses, despite some differences between them. The visual score is higher for the Volvo B10M. Concerning the global score, the one of the B10M is slightly higher than the one of the Volvo B58. This corresponds to an improvement between the two model, with the oldest having the worst score.

4.2.4 Air exchange rate

Figure 8 allows representing the CO_2 concentration decay. It is possible to distinguish the exponential curve it takes for both buses. An exponential fitting is then possible, and the computation of the AER can be done using the equation presented in the section 3.2.4.

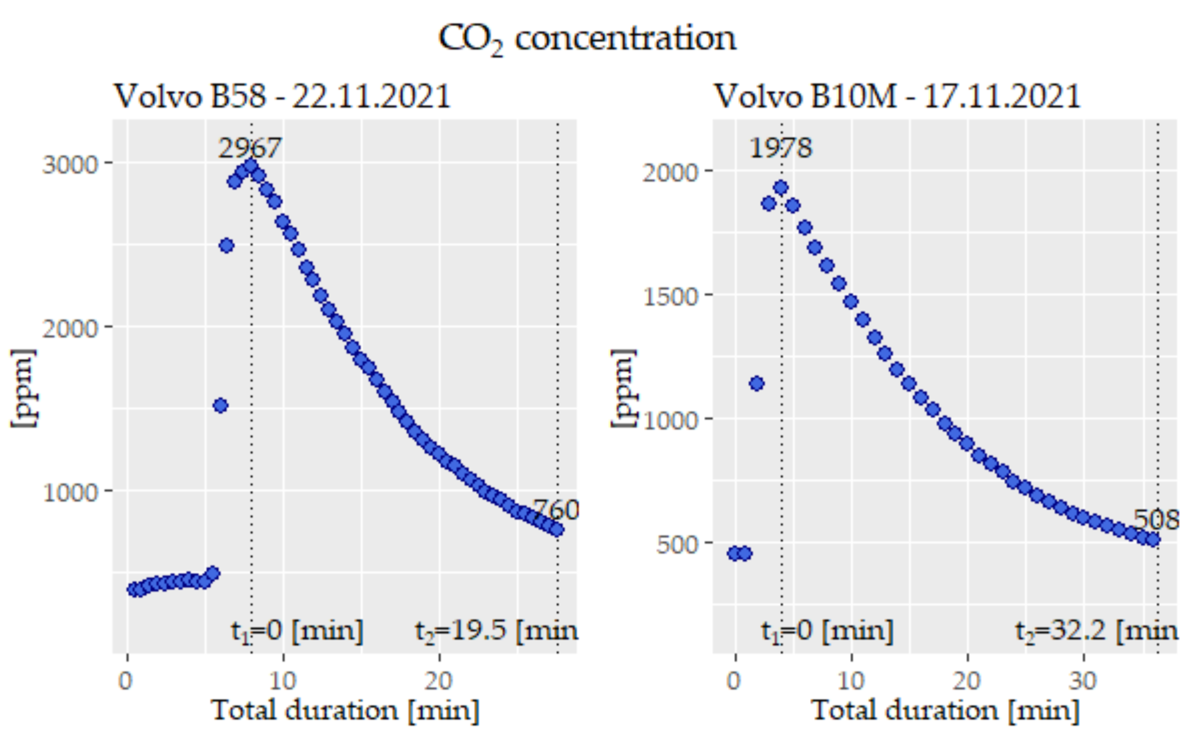


Figure 8: CO_2 concentration, used as a tracer gas for the evaluation of air exchange rate by the tracer gas decay method

The computed AER, ventilation and maximal occupancy based on this ventilation are presented in Table 8. Comparing the AER of the two buses, it appears that this rate is 40% lower for the Volvo B10M than the Volvo B58. However, both are too low. Moreover, considering the estimated ventilation of 8 liter per second per person, it would be enough for only 9 people in the Volvo B58 and only 6 in the Volvo B10M. It is far away from their maximal capacities of 100 and 90 persons respectively.

Table 8: Summary of the AER, ventilation, and maximal occupation based on this ventilation computation

BUS	Duration [h]	CO2 concentration [ppm]		AER [1/h]	Estimated ventilation [m^3/h]	Estimated volume [m^3]	Possible occupancy for given ventilation (# person)
		At t_1	At t_2				
B58	0.325	2967	760	4.19	221.2	52.78	9
B10M	0.536	1978	512	2.53	145.8	57.82	6

4.2.5 Electromagnetic field

As said in Murphy's Law: Anything that can go wrong will go wrong [61]. It is what has happened with the measures of electromagnetic fields.

There is no result for the electric and magnetic field at low frequencies (5 to 100 kHz) for the Volvo B58 as it has not been possible to connect the probe to the device. Moreover, the data has not been recorded while doing the simulations for the Volvo B10M, despite the manipulations that were done correctly, so there is no result for the electric fields at frequencies between 100 kHz and 7 GHz.

The figure below shows the variation of the electric fields during the three simulations with the Volvo B58. It is important to note that a smartphone and a connected watch have been turned on and not on plane mode to record the information about the tours. However, they have been a couple of meters away from the measuring device, which should lower their impact on the measurements. All other similar devices have been set in plane mode.

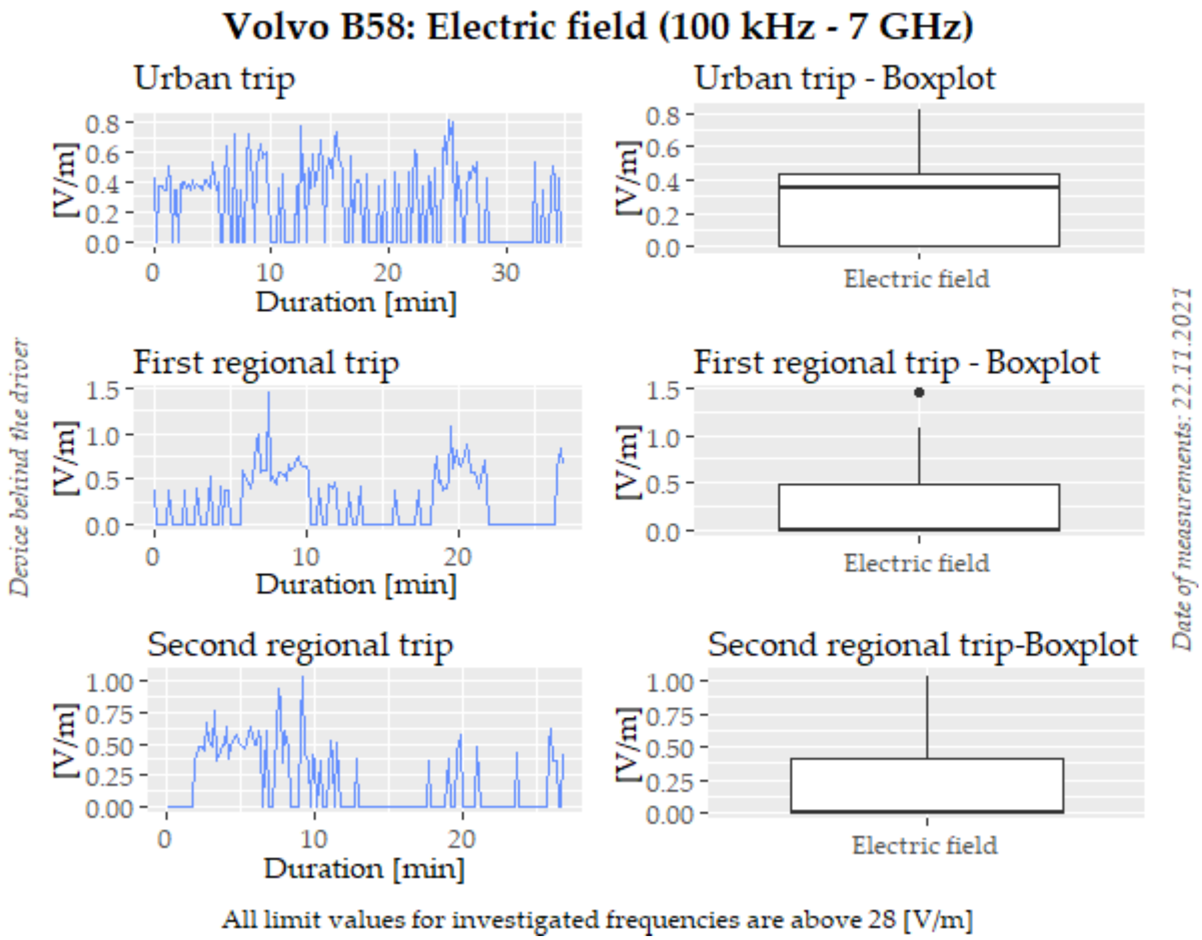


Figure 9: Variation of the electric field during the three simulations - Volvo B58

During many minutes, the electric fields are below the detection value. The detectable ones are low, less than 5% of the lowest limit value, except for one peak during the first regional trip. The exposition and the mean value over 6 minutes are shown in the table below.

Table 9: Average electric field exposition and mean value over six minutes

Bus	**Simulation type**	**Exposition to EF [V/m]**	**Max mean values over 6 minutes [V/m]**
Volvo B58	**Urban**	0.25	0.38
	Regional	0.21	0.51

The exposure during the regional trips is slightly lower than during the urban simulation. However, the average over 6 minutes is higher for the regional simulation than the urban one. Despite this, they remain well below the limit values as they correspond to 1% of the lowest limit value.

For the Volvo B10M, the exposure to electric field at low frequencies is 0.66 V/m and the magnetic field is 0.24 μT. Both fields are far below the limit values.

4.2.6 Particulate matter PM_{10}

Figure 10 shows the variation of PM_{10} concentration during the urban simulation for both buses. As it can be seen, there are extreme values for both buses (cf Boxplot of Figure 10), but the main part stays in or just below the range of the daily average for the corresponding day of measurements.

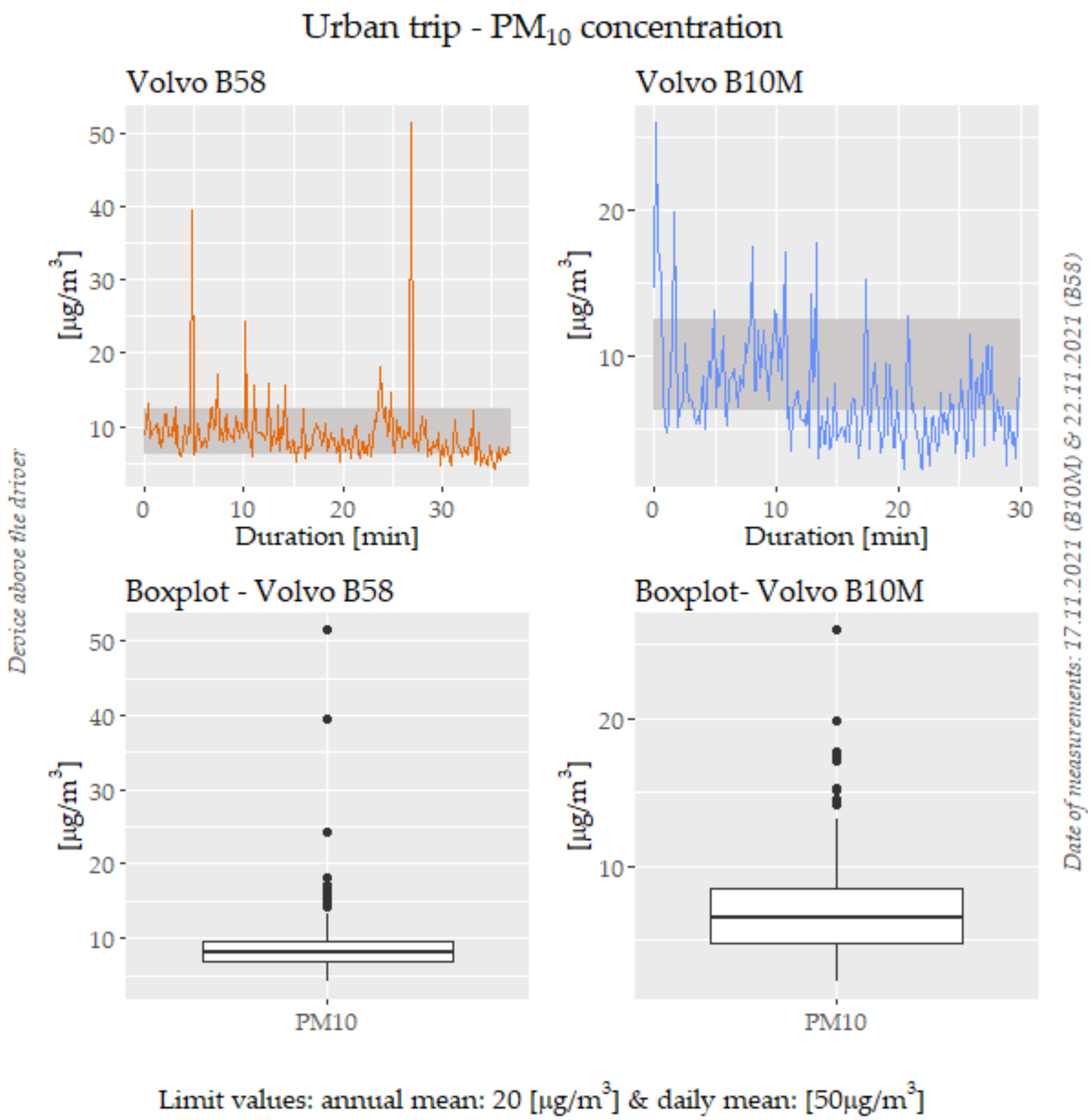


Figure 10: Variation of PM_{10} concentration during the urban trip for buses. The grey rectangle corresponds to the daily average range for the region of Moudon (Vaud, Switzerland)

Figure 11 corresponds to the variation of concentration of PM_{10} during the first regional simulation for both buses. We can see that, for both buses, there are a few extreme values with only two above the annual mean for the Volvo B58. Most of the time the concentration of PM_{10} for the Volvo B58 stay in the range of daily average, but for the Volvo B10M, it is mainly below that average.

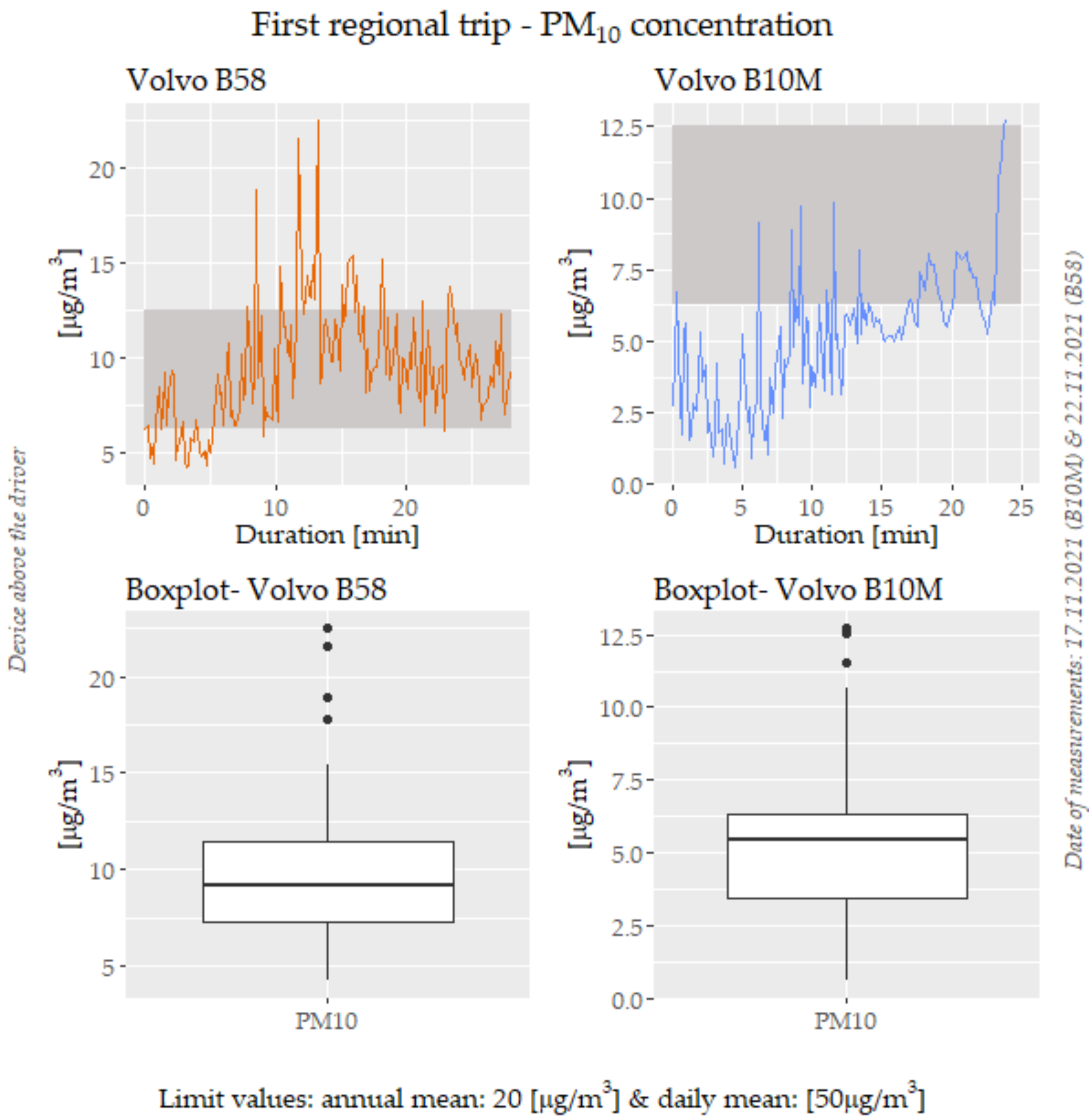


Figure 11: Variation of PM_{10} concentration during the first regional trip for both buses. The grey rectangle corresponds to the daily average range for the region of Moudon (Vaud, Switzerland)

The variation of the concentration of PM_{10} during the second regional simulation is presented in Figure 12. There are extreme values only for the Volvo B58, but they are mainly below the annual limit value. For both buses, the concentration stays below their corresponding daily average.

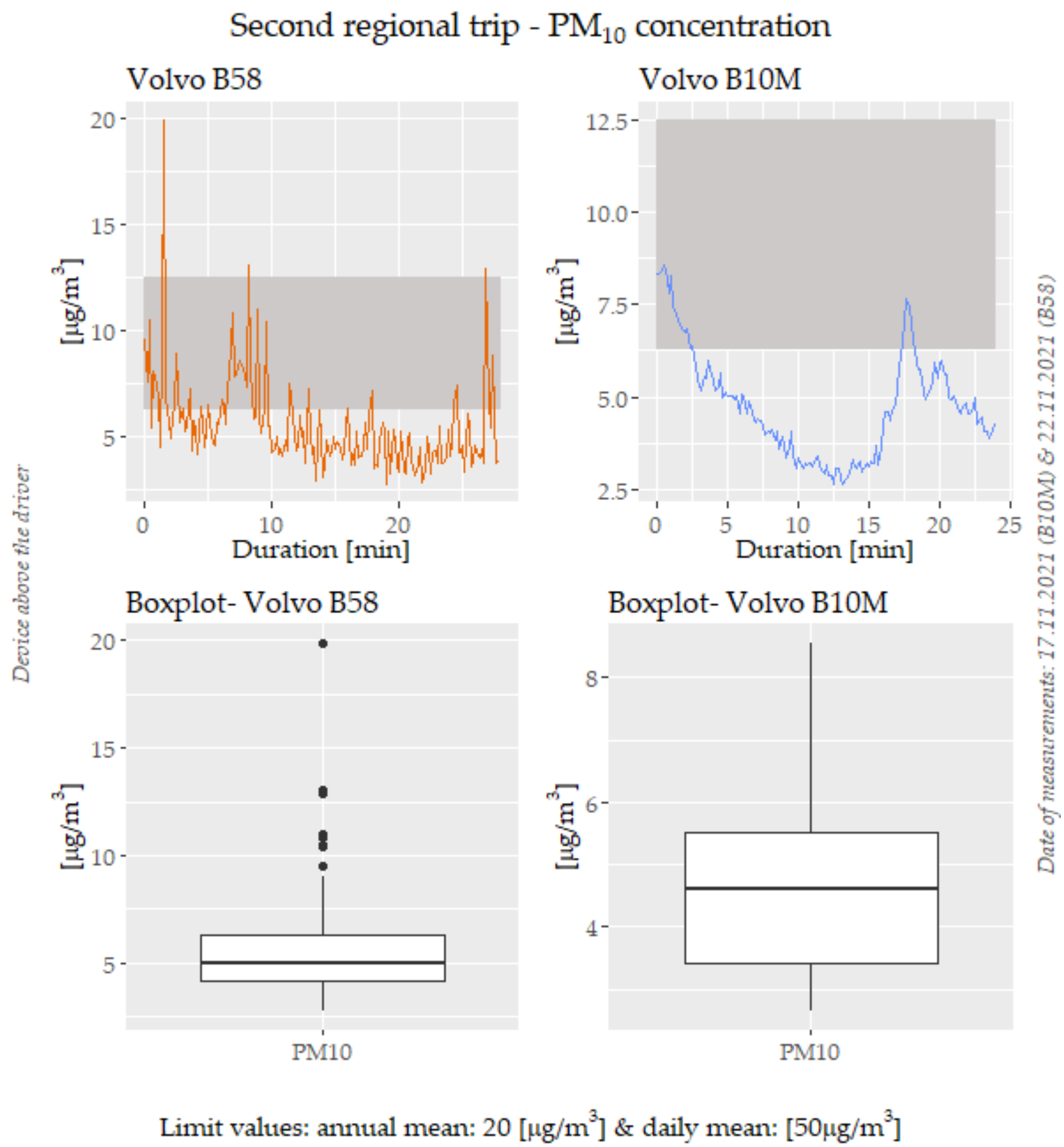


Figure 12: Variation of PM_{10} concentration during the second regional trip for both buses. The grey rectangle corresponds to the daily average range for the region of Moudon (Vaud, Switzerland)

As seen in Table 10, the concentration is slightly higher for the Volvo B58 than the Volvo B10M, but both stay in the lower part of the daily average for their corresponding day of measurement for the urban simulation. Concerning the regional simulations, the average is higher for the Volvo B58 than the Volvo B10M. The dose for the Volvo B58 is within of the daily average range, but for the Volvo B10M it is below. The ratio is computed with the range of daily average [52] as there is not a more precise number. We observe that the Volvo B58 has higher ratios than the Volvo B10M.

For both simulations, the Volvo B58 might accumulate particles inside. It is the same situation for the urban simulation of the Volvo B10M, but for the regional simulation, there is a filtration effect.

Table 10: Average PM_{10} concentration and ratios between the average PM_{10} and the daily average from OFEV

Bus	Simulation type	PM10 concentration [µg/m3]	Range of ratio
Volvo B58	Urban	8.87	0.7-1.4
	Regional	7.50	0.6-1.2
Volvo B10M	Urban	7.24	0.6-1.2
	Regional	4.96	0.4-0.8

4.2.7 Noise

Concerning the data of noise for the Volvo B58, the extreme values at 0 for the peak noise level (L_{peak}) are taken out as they probably correspond to malfunction of the device. Moreover, only the result of the device placed on the driver's shoulder is presented as it corresponds more precisely to the dose of noise perceived by the driver. We have not used the same device for both buses, the choice depends on the availability of the devices because several projects are carried out in parallel within Unisané. For the Volvo B58, we have used the dosimeters 4445 with a recording frequency of 5 seconds and for the Volvo B10M, it was the dosimeter 4448 with a recording frequency of 1 minute. We have chosen to represent the data with their corresponding time step to avoid losing information by averaging the data to a 1-minute time step for the Volvo B58.

Figure 13 shows the noise variation during the urban trip. For the Volvo B58, there are no extreme values but there are some for the Volvo B10M for both noise levels. Furthermore, the equivalent noise level stay under the limit value for the Volvo B10M, while it goes above for some of the data of the Volvo B58. Yet, the peak level is below the limit value for both buses.

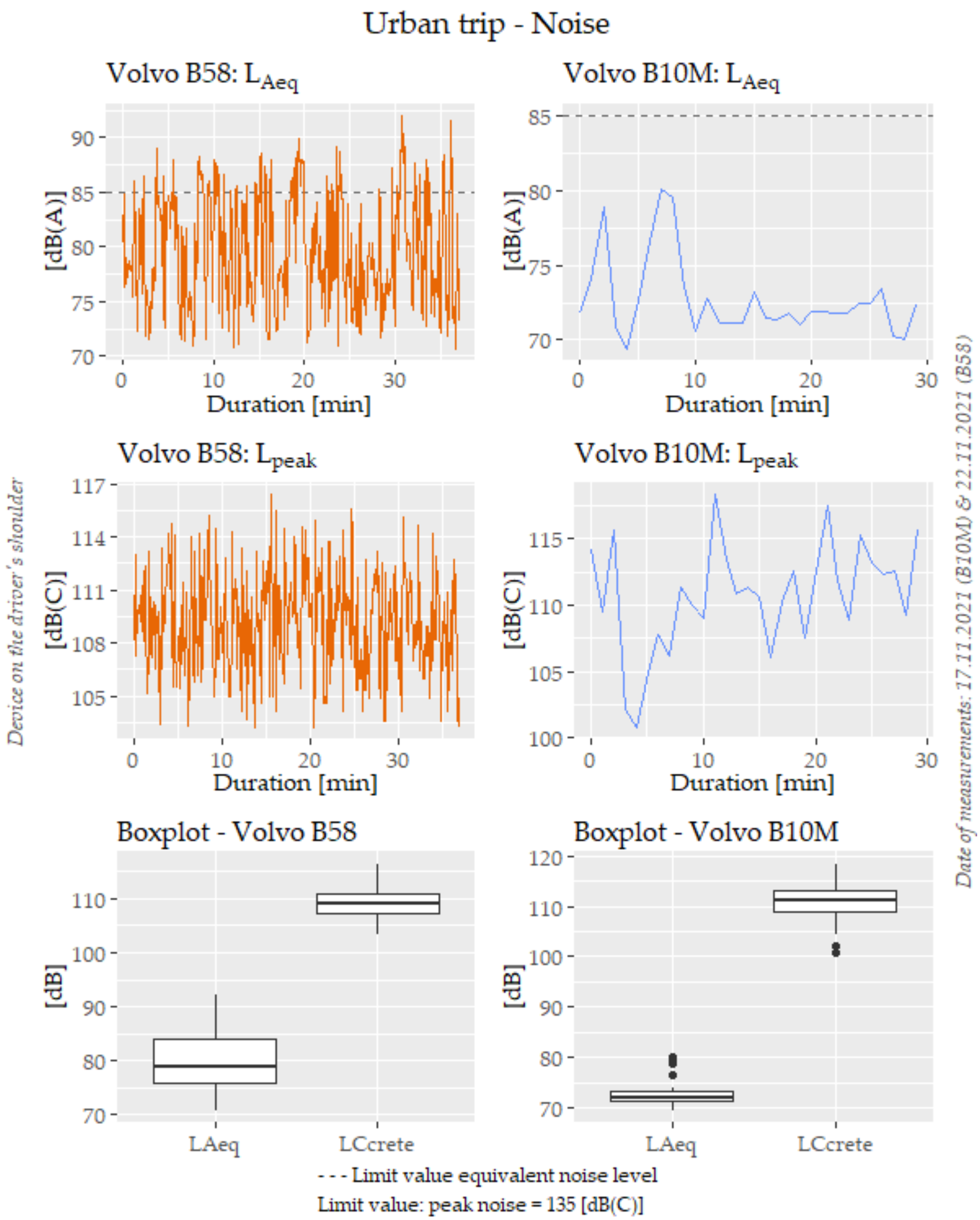


Figure 13: Variation of noise during the urban trip for both buses. With LC_{crete} corresponding to the peak level.

The variation of the noise levels for the first regional trip is shown in Figure 14. In this case, both buses have extreme values. Again, the equivalent level is below the limit value for the Volvo B10M and is a few times above for the Volvo B58. Looking at the peak level, we can notice that it stays below the limit value for the Volvo B10M, but some data is above the limit for the Volvo B58, those are considered as extreme values.

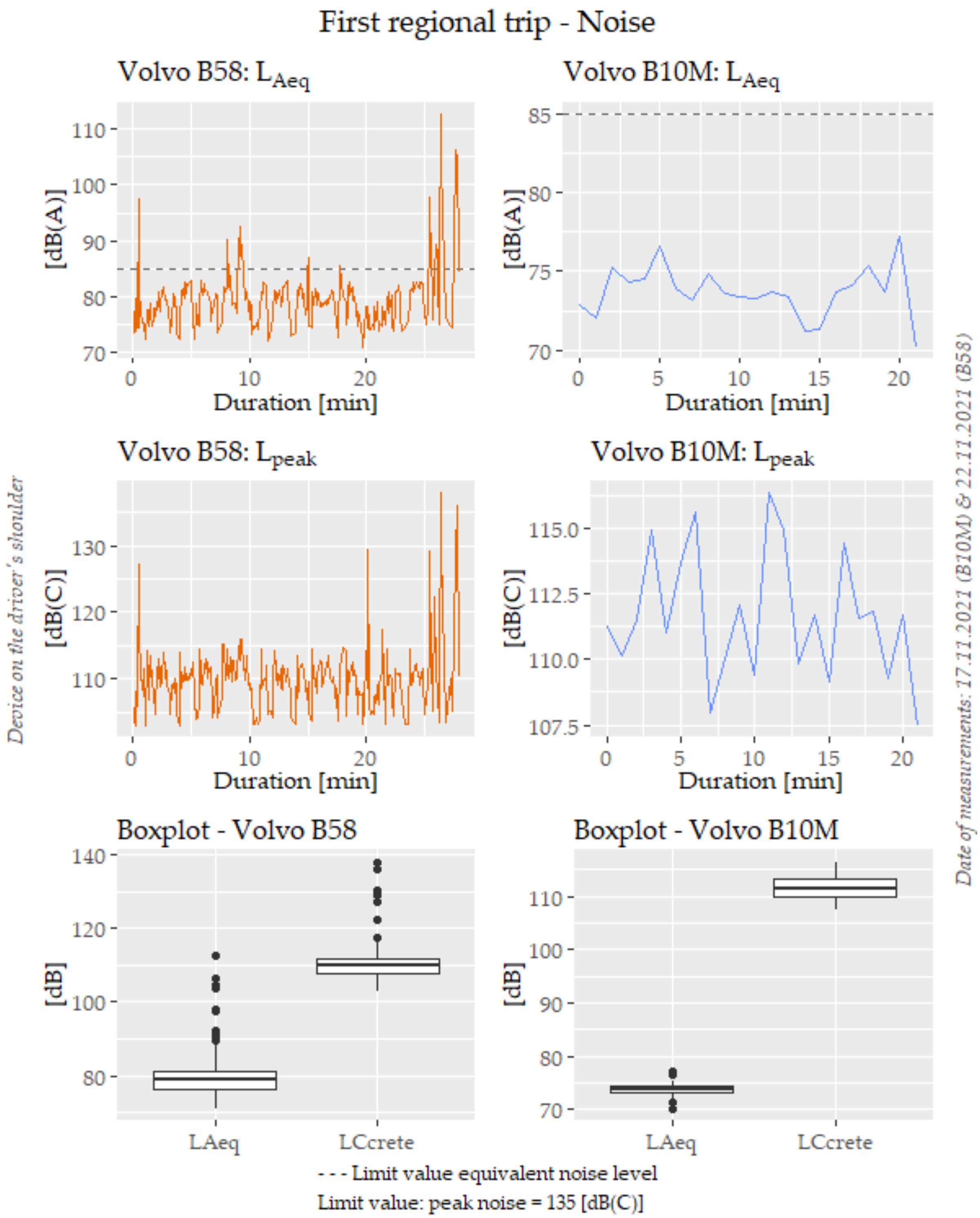


Figure 14: Variation of noise during the first regional trip for both buses. With LC_{crete} corresponding to the peak level.

Figure 15 shows the variation of the second regional simulation. The observations are the same as for the first regional trip. The only difference is on the extreme values of the Volvo B10M, where there is only one for the peak level.

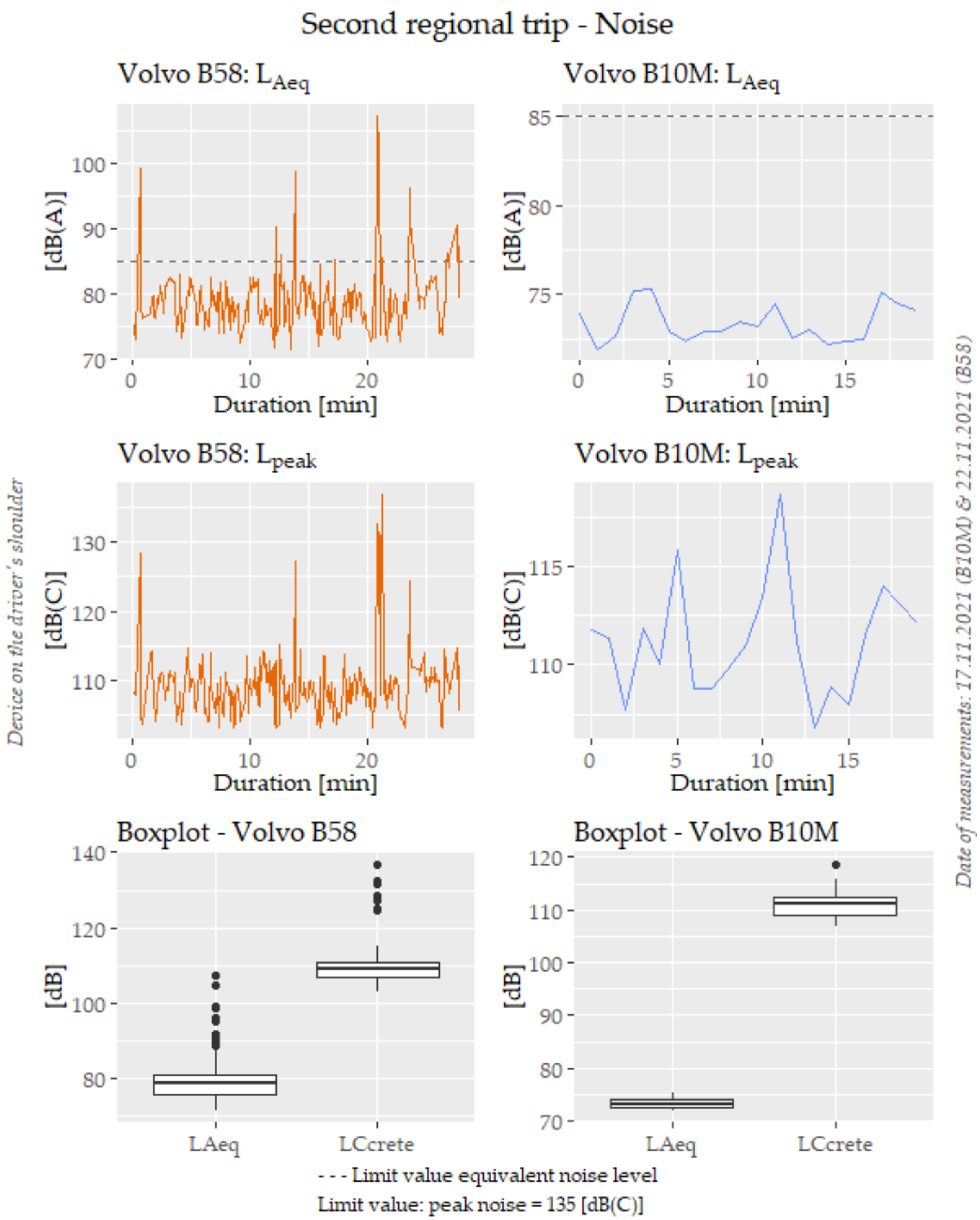


Figure 15: Variation of noise during the first regional trip for both buses. With LC$_{crete}$ corresponding to the peak level.

Table 11 shows the average of equivalent noise level and the peak level. The average of the equivalent noise is higher for the Volvo B58 than the Volvo B10M, in addition, the regional simulation of the Volvo B58 has an average above the limit value. However, the mean peak levels are similar, and they are all below the limit value.

Table 11: Average of noise exposition. In *dark red*: value exceeding the maximal equivalent noise level

Bus	Simulation type	Noise- L_{Aeq} [dB(A)]	Noise- L_{peak} [dB]
Volvo B58	Urban	83.6	111.16
	Regional	*88.34*	116.47
Volvo B10M	Urban	73.79	112.39
	Regional	73.77	112.31

4.2.8 Vibrations

Figure 16 shows the variations of vibrations of the seat, computed as root mean square, for both buses in the three directions. For both buses, there are many extreme values. Furthermore, most of the vibrations are above the action value, but most of them are below the limit value in the three directions. The data above the limit value is the most abundant in the z-direction for both buses, corresponding to stronger up and down vibrations.

The variation of the vibration of the seat for the regional simulation is represented in Figure 17. We can observe that most of the values are between the action and limit value in the x-direction (left and right) for both buses. A higher proportion of values are below the alert value in the y-direction (forward and backward) for both buses. Again, the direction with the most extremes is the z-axis for both buses. However, all three directions have extremes values for both buses, but the z-direction has the largest range of extreme values.

Figure 18 shows the variation of vibrations of the floor for both buses. We notice that most of the data in the x and y-directions are below the action value for both buses, and none of them goes above the limit value. Again, the z-direction has the most extreme values for both buses and a higher proportion of data are above the alert values. The observation on the extreme value is the same as for the first regional trip.

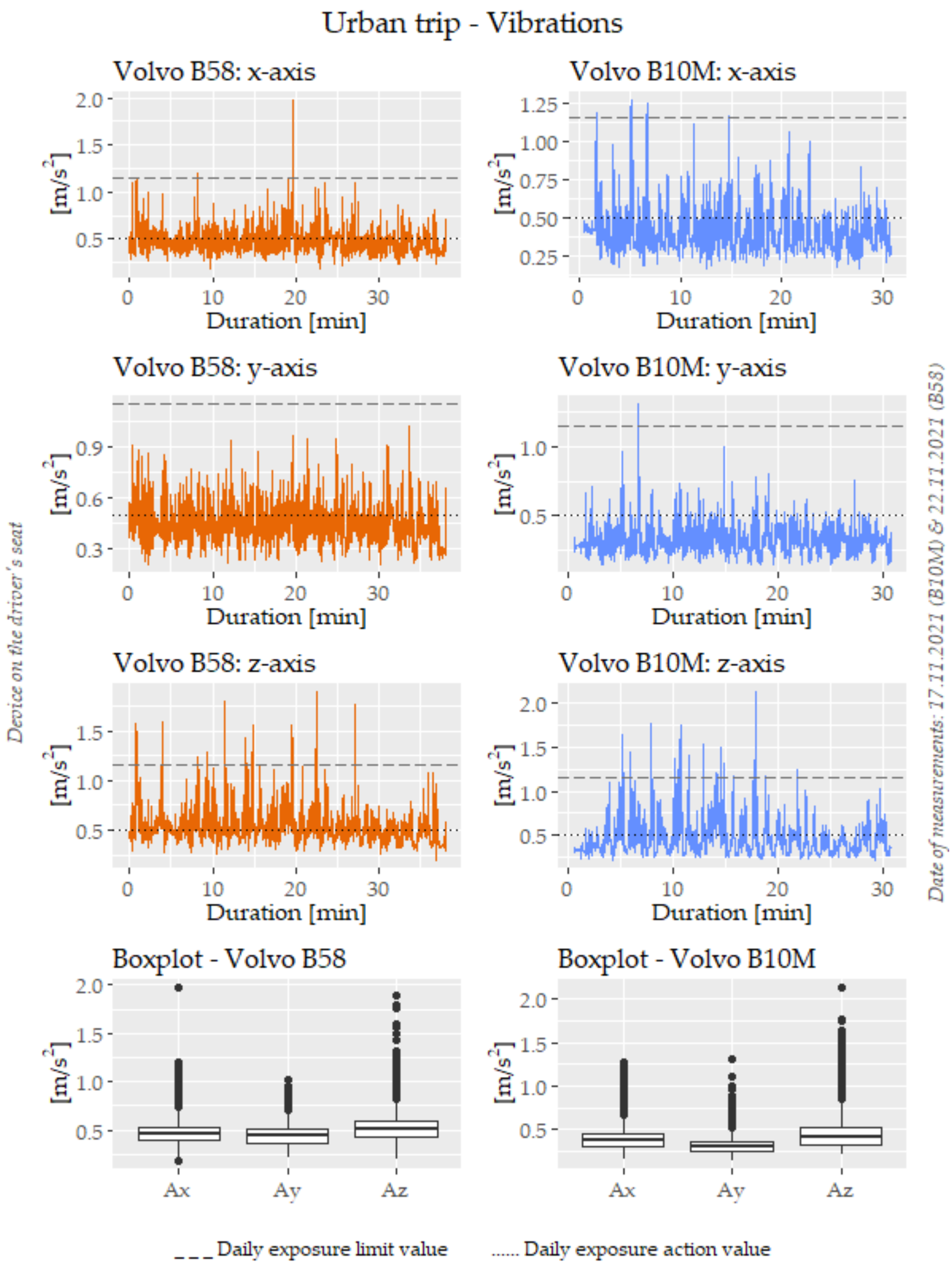


Figure 16: Variation of vibrations of the seat during the urban trip - Volvo B58 and Volvo B10M

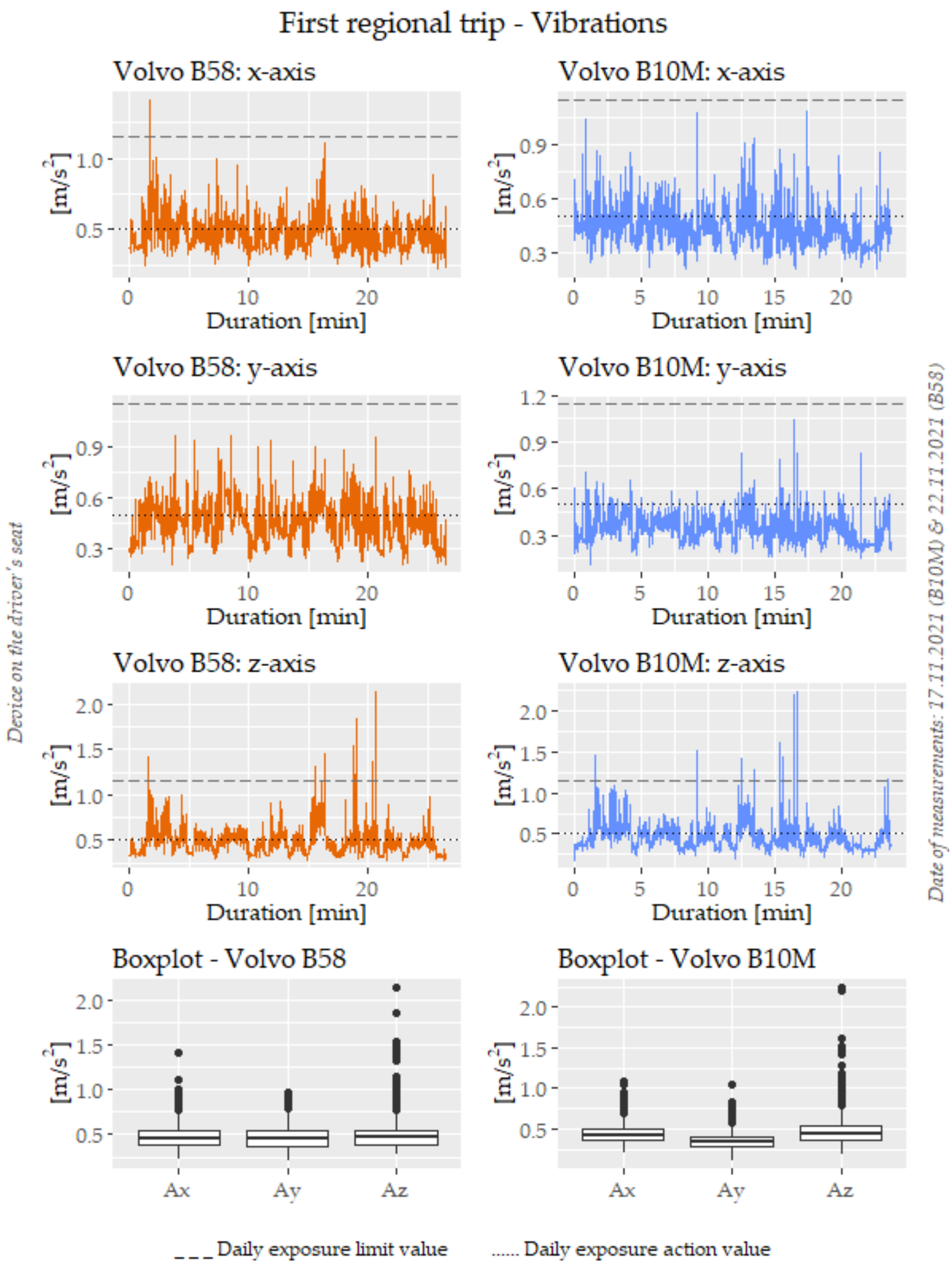


Figure 17: Variation of vibrations of the seat during the first regional trip - Volvo B58 and Volvo B10M

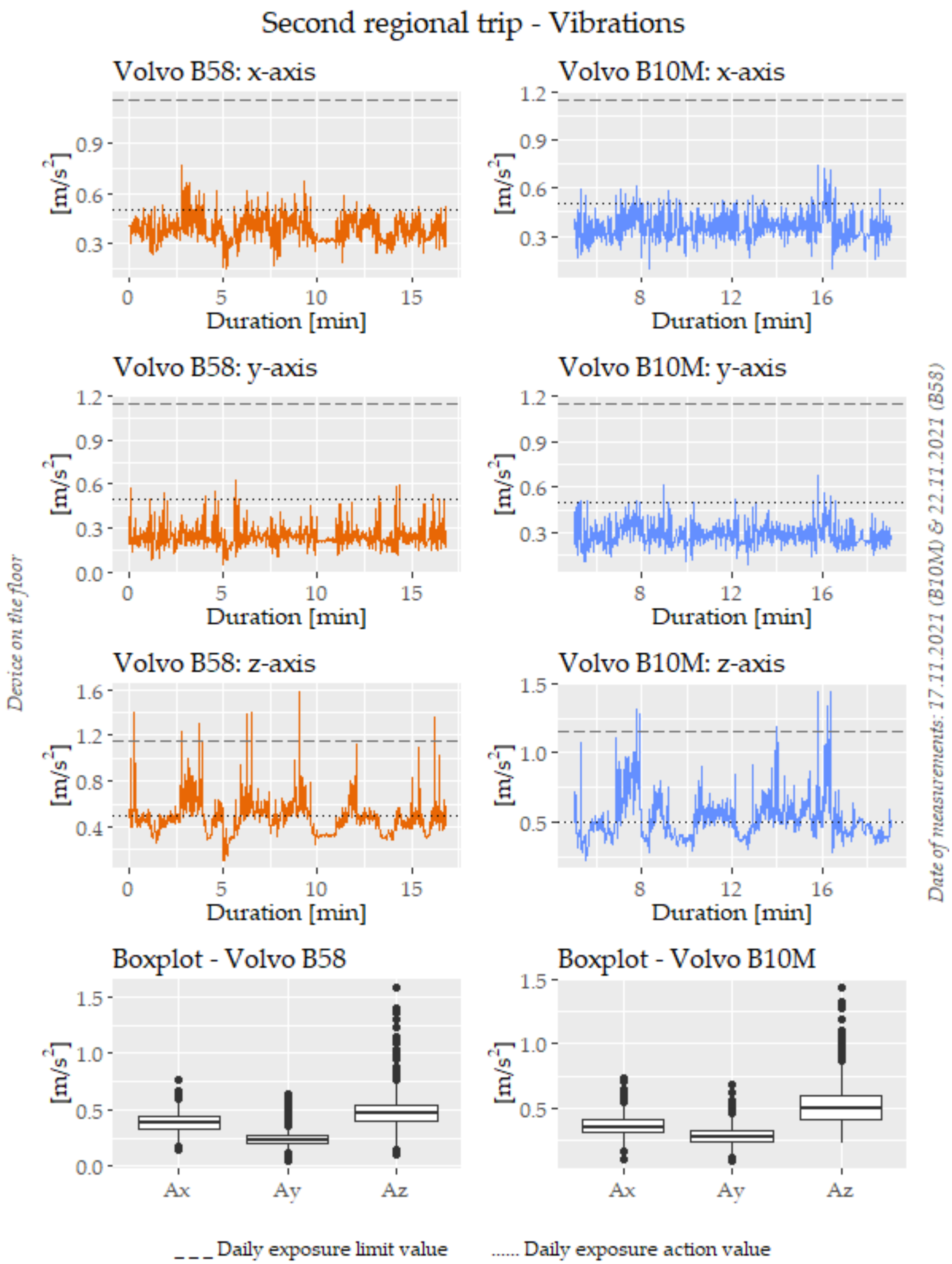


Figure 18: Variation of vibrations of the floor during the second regional trip - Volvo B58 and Volvo B10M

The Table 12: Summary of the vibrations for both buses. In **dark red**= higher than the limit value, *orange*= higher than the alert value presents the equivalent 8 hours vibrations of the three axis and the daily exposure. We can notice that for both buses, those daily exposures are above the alert values. However, the vibrations are lower for the B10M than the B58, with the biggest difference being for the urban simulation. For the B58, there is no difference between both types of simulation. For both buses, the highest vibrations of the seat occur in the x-direction for the two types of simulations. Before the simulation, a rough road is taken to go from the bus depot and the start point of the urban simulation. The vibrations have been recorded, but not shown in this report. For that road, the vibrations of both buses are above the limit value, however, the vibrations are lower for the Volvo B58 than the Volvo B10M, which is the opposite situation than in the simulations. In addition, the highest value is also in the x-direction for the Volvo B10M, but for the B58, it is in the z-direction.

Table 12: Summary of the vibrations for both buses. In **dark red**= higher than the limit value, *orange*= higher than the alert value

		A(8) [m/s²]			Daily exposure
	Type	**X-axis**	**Y-axis**	**Z-axis**	
Volvo B58	Rough road	*0.80*	*0.64*	**1.19**	**1.19**
	Urban	*0.66*	*0.62*	*0.53*	*0.66*
	Regional	*0.66*	*0.64*	0.49	*0.66*
Volvo B10M	Rough road	**1.27**	*0.65*	**1.24**	**1.27**
	Urban	*0.58*	0.46	0.49	*0.58*
	Regional	*0.62*	0.49	0.48	*0.62*

The transmissibility of the seat is shown in the Table 13. We notice that for the Volvo B58, the seat intensifies the vibration in all three directions, with the strongest effect in the y-direction and the lowest in the z-direction. For the Volvo B10M, the seat intensifies the vibrations in the x and y-directions; however, it attenuates the vibrations in the z-direction.

Table 13: SEAT values for both buses. Values above 100% indicates that the seat intensify the vibrations from the floor

	SEAT [%]		
	X-axis	**Y-axis**	**Z-axis**
Volvo B58	123.2	186.0	100.6
Volvo B10M	124.0	120.6	90.8

4.2.9 Seat temperature

Figure 19 shows the variation of temperature inside the Volvo B58. It varies from 13.3°C to 17.1°C. It corresponds to a 3.8°C difference with the heater at maximum. The average is 15.3°C.

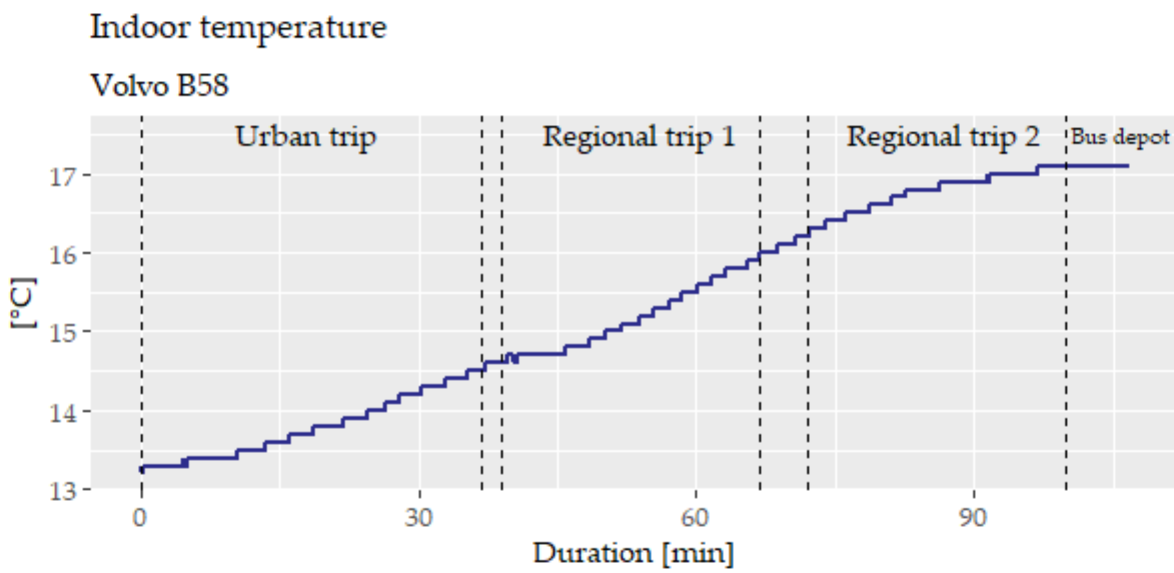


Figure 19: Indoor temperature of the Volvo B58 for the duration from the beginning of the first simulation to the end at the bus depot

After a ride of 35 minutes without seat pad, the temperature of the center of the seat of the Volvo B58 is 21.5°C, the maximum is 23.1°C, on the right side, and the minimum is below 18°C in the front part of the seat. After 1 minute with nobody sitting, the temperature goes down to 18 °C in the center of the seat, that correspond to a decrease of 3.5°C. The maximal temperature decreases by around 3°C, it is at 20°C. But the minimum is below 14°C, which correspond to a decrease of around 4°C. Therefore, the seat releases heat rapidly. To note, the front door is opened during the measurements, allowing cold air (4°C according to agrometeo.ch [62]) to enter.

The temperature of the seat and its variation are shown on the figure below.

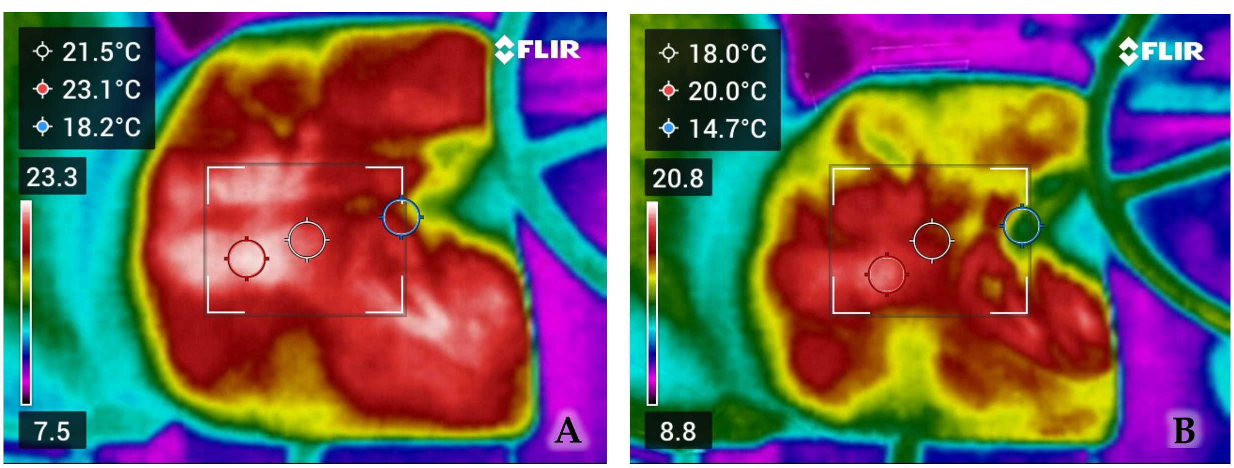


Figure 20: Thermal picture of the seat temperature of the Volvo B58. A) After around 30 minutes ride, B) 2 minutes after picture A

The indoor temperature of the Volvo B10M, which variation is shown in Figure 21, varies between 14.3°C and 25°C. It is a 10.7°C difference with the heater at varying from half to maximum. The average is 19.4°C.

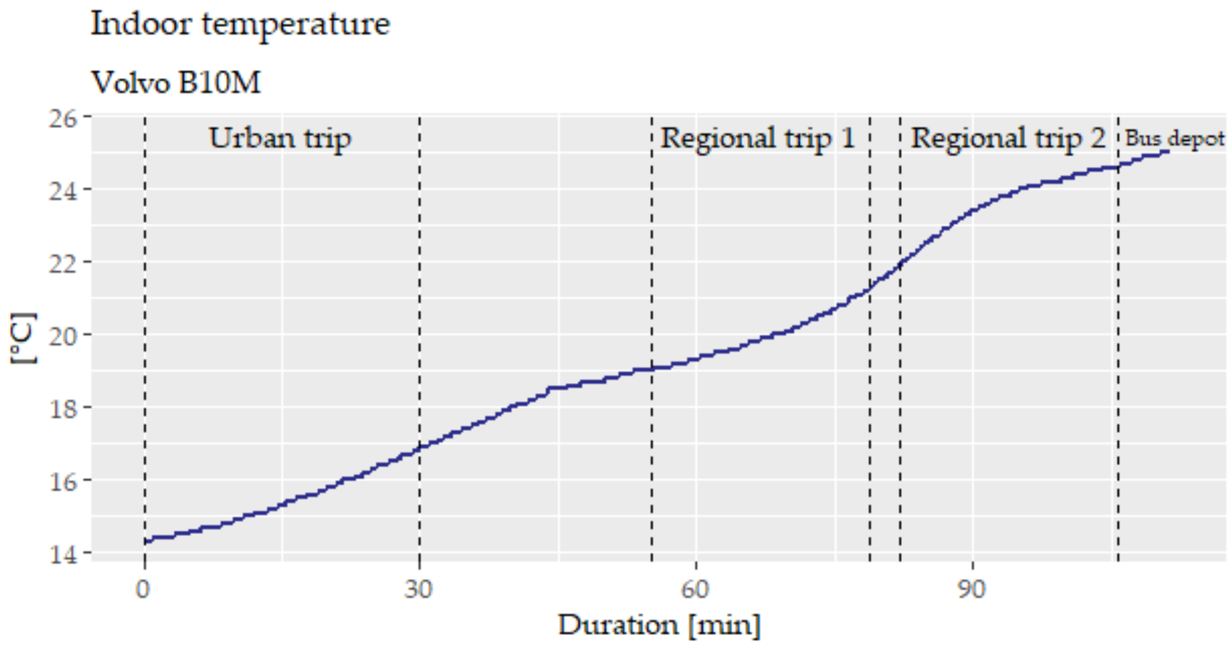


Figure 21: Indoor temperature of the Volvo B10M for the duration from the beginning of the first simulation to the end at the bus depot

After around 30 minutes ride without seat pad, the Volvo B10M seat temperature rises to a maximum of 31.4°C, which is slightly to the right of the center as seen on Figure 22. However, the temperature in the middle of the seat is a bit lower at 30.7°C and the lowest temperature, at the front of the seat, is below 26°C. After 1 minute without the sitting driver (cf. Figure 22), the maximal temperature goes down to 26.7°C, that is around 5°C less, and the temperature in the middle is also lowered by about 5°C, it is then at 25.9°C. However, the lowest temperature reduces less, by about 2-3 °C. The seat seems to release the heat rapidly. To note, the front door is opened during the measurement, allowing cold air (5°C according to agrometeo.ch [62]) to enter.

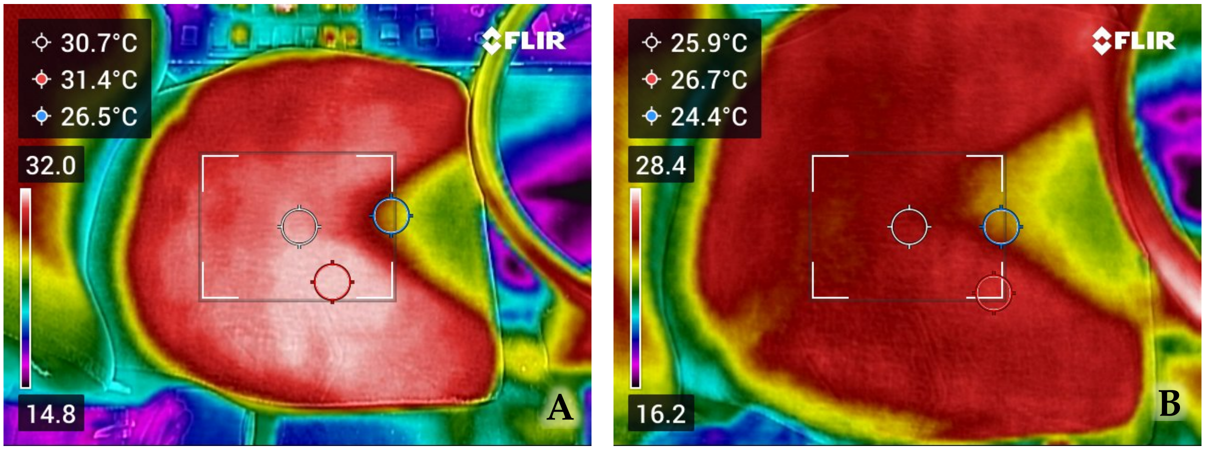


Figure 22: Thermal picture of the seat temperature of the Volvo B10M. A) After around 30 minutes ride, B) 2 minutes after picture A

4.3 Construction of the Bus exposure matrix

The BEM is a multidimensional table providing, for each bus the level of exposure corresponding to the hazards related to this bus [13, 14]. As not all the bus models present in Switzerland can be measured, we include in the BEM some bus characteristics as the dimensions and the information of the engine. These characteristics are used to identify similar buses so that exposures can be extrapolated to unmeasured bus models.

Our BEM is composed of 26 bus characteristics and 12 exposure values. The first draft of the BEM is presented in Table 14. It is an evolving work; it might change as we add bus models.

Table 14: Bus Exposure Matrix (BEM) - first draft

	Bus 1	Bus 2	Bus 3	Bus 4
Type of trip	Regional	Urban	Regional	Urban
Brand	Volvo	Volvo	Volvo	Volvo
Model	B58	B58	B10M	B10M
Type of bus	Midi	Midi	Solo	Solo
# passenger (max)	102	102	90	90
Period of service	1972-2003	1972-2003	1983-2015	1983-2015
Length [m]	9.3	9.3	11.8	11.8
Width [m]	2.4	2.4	2.5	2.5
Height [m]	3.2	3.2	3.2	3.2
Full load weight [kg]	16 000	16 000	16 500	16 500
Gearbox	Semi-automatic	Semi-automatic	Automatic	Automatic
Fuel	Diesel	Diesel	Diesel	Diesel
Number of cylinders	6	6	6	6
Engine power [bhp]	230	230	230	230
Cubic capacity [cm^3]	9599	9599	9599	9599
Engine position	Mid mount	Mid mount	Mid mount	Mid mount
Soundproofing	NO	NO	NO	NO
Euro norm	None to 1	None to 1	None to 1	None to 1
Suspension	Air over leaf spring	Air over leaf spring	Air spring	Air spring
Power assistance	Hydraulic	Hydraulic	Hydraulic	Hydraulic
Driving aids	NO	NO	NO	NO
Air conditioning	NO	NO	NO	NO
Heater	YES	YES	YES	YES
Seat	Grammer Bremshey	Grammer Bremshey	Grammer Bremshey	Grammer Bremshey
Low floor	NO	NO	NO	NO
Air exchange rate [h^{-1}]	4.19	4.19	2.53	2.53
Global ergo. score	34.4	34.4	40.6	40.6
Visual score	50.0	50.0	83.3	83.3
Biomechanics score	26.9	26.9	26.9	26.9
EF (5-100 kHz) [V/m]	-	-	0.66	0.66
Magnetic fields [µT]	-	-	0.24	0.24
EF (100 kHz-7GHz) [V/m]	0.21	0.25	-	-
PM_{10} ratio	0.6-1.2	0.7-1.4	0.4-0.8	0.6-1.2
Noise [dB(A)]	88.3	83.6	73.8	73.8
Vibration [m/s^2]	0.66	0.66	0.62	0.58
SEAT (x/y/z)	123/186/101	123/186/101	124/121/91	124/121/91
Seat temperature after 30 minutes ride (max) [°C]	23.1	23.1	34.4	34.4

5 Discussion

Despite searching all the PTC websites, not all companies specify the bus models used. The inventory is then not complete but covers around three fourth of the 75 PTC. We have already contacted 7 PTC to complete their inventory, only two of them have not answered yet. Additionally, an official register [63] has been found, but it includes scholar bus and buses from private companies, which are not considered for this study. It has been used as a support to find the registration number to have official information on the bus models on the website *typenscheine.ch* [64].

The two models measured are two models from the same brand and the Volvo B10M is the successor of the Volvo B58. They have a similar chassis, which differences are due to technological innovations. Their evaluation allows seeing the impact of the technological evolution over a decade.

It is important to note that the bodywork is dependent on the coachbuilder, meaning that the exact same chassis might end up as very different buses with not the same passenger capacity. This adds a level of complexity for the construction of the BEM.

Although both buses have the same seat model, they do not have the same seat score. They do not have for example the same height of backrest. In addition, the age of the seat might influence the results, as the controls for adjustments are harder to use on the oldest bus, the Volvo B58. Nevertheless, being the same model of seat, they should be similar. The possible explanation for this difference is the age gap (16 years) between the two buses, as the seats are the originals of these buses; they have the same age gap. The rest of workstation has evolved between the two bus models. The greatest improvement is on the visual aspect of the dashboard. The blinking signals with their name in Swedish written below have been replaced by clearer pictograms. This contributes to the better visual score of the Volvo B10M. Concerning the pedals, the Volvo B58 is a bit better than the Volvo B10M as the range of angles fits the criteria. This is the only area where the Volvo B58 has a better score than the Volvo B10M. For all the other categories, either they have the same score or the Volvo B10M is better. Anyway, both buses do not offer the possibility of having an ergonomic workstation, especially concerning the biomechanical categories. This is linked to health issues, such as musculoskeletal troubles [19, 21].

The AER is not sufficient for any of the buses. However, this component is important for long driving periods. In an urban line and event in most regional lines, the interval between two stops is short, between 1 to 5 minutes. This means there is a short period of accumulation of pollutant inside a bus and a frequent mixing with outdoor air at each stop when the doors open. For long distance travel with no stops, the CO_2 concentration will tend to increase and might influence the well-being of the driver by provoking headache, difficulty to concentrate or lethargy [34].

It is not possible to compare the results of the electromagnetic fields measurements, as we do not have a complete set. However, they are greatly dependent of the on-board equipment and the outdoor environments. When those buses were in circulation, the mobile phone were not widespread, it is the main source of electromagnetic fields nowadays [36, 65]. This parameter will have a greater impact in modern bus, which are equipped with many connected devices and almost everybody has a mobile phone on them, including the bus driver.

The concentration of PM_{10} is highly dependent on the outdoor environment. There has been less traffic during the regional simulation of the Volvo B10M than the Volvo B58, which has been closer to the rush hours. However, the traffic has been similar for the urban simulations of both buses. Even with a similar traffic, the concentration of PM_{10} is higher for the Volvo B58 than the Volvo B10M. With this information, we can hypothesize that the Volvo B10M has a better filtration capacity than the Volvo B58, as the outdoor PM_{10} concentration has been probably similar during the two urban simulations.

The noise equivalent level is high, above the limit value, for the regional simulation of the Volvo B58, while it is just below the limit value for the urban simulation. But, for the Volvo B10M, the equivalent noise level is more than 10 dB(A) below the limit value. This corresponds to a great improvement between the buses as there is a difference between 10 to 15 dB(A). The high noise level of the Volvo B58, above the limit value, is linked to hearing loss [32].
Nevertheless, the measurements have been recorded on almost empty buses; there have been only a second driver and three members of the project team. Buses at full capacity might be noisier. Moreover, the measurements have been done outside the rush hours. There has been little outside traffic noise. Therefore, the main source of noise is the engine.

The vibrations are too high for both buses, they will have an impact on the health of the bus drivers [3, 22, 45].However, there is an improvement between the Volvo B58 and the Volvo B10M. The newer bus has a bit lower level of vibrations. It is interesting to note that for the x-axis, the vibrations of the floor are higher for the Volvo B58, but for the other axes, they are higher for the Volvo B10M. This is the opposite of what was expected. It seems that either the engine produces fewer vibrations, or the suspensions attenuate them better for the Volvo B58 than the Volvo B10M. For both buses, the highest exposure to vibration is in the x-direction.
The seat, which is supposed to attenuate the vibrations, acts as an intensifier for all directions for the Volvo B58 and in the x and y-direction for the Volvo B10M. The only time the seat attenuates the vibrations is in the z-direction for the Volvo B10M. It has almost the same amplification capacity in the x-direction for both buses. However, the seat of the Volvo B58 highly intensifies the vibrations in the y-direction (ratio of 186 %), without this amplification, the daily exposure would be below 0.5 m/s^2, the alert value. As mentioned previously, both buses have the same

model of seat, but it reacts differently for the two buses. That difference might come from fatigue of the materials; the seat of the Volvo B58 is 16 years older than the one of the Volvo B10M.

The seat temperature is dependent on the seat materials but also on the ambient temperature. We notice that with the same seat model, the temperature differs for the two buses. The main difference between the simulations is the ambient temperature, which is higher in the Volvo B10M. Its heater is more efficient than the one in the Volvo B58 when both have been put to the maximum. In fact, the heater has been lowered in the Volvo B10M, as it was too efficient. There is a difference of 6°C for the indoor temperature, and for the seat temperature at the center, the difference is about 9°C. This difference is greater than the indoor temperature difference. Anyway, both temperatures are below the human body temperature and will therefore not harm the male fertility or be uncomfortable [29, 33]. It is interesting to notice that the temperature of the seat decreases rapidly. This means that whenever the driver stands up, the seat will cool down rapidly. However, it is not possible to compute the heat exchange rate as there too many missing variables. Those results are for cold period as the measurements have been recorded in November in Moudon. In hot summer days, the seat temperature might increase and become uncomfortable, as there is no seat ventilation system.

The BEM includes elements from the bus inventory mentioned in section 4.1. We keep the characteristics allowing to differentiate the buses but also to find the similarities. Part of the characteristics have been reported as driving aids (elements 25 to 34 of the Annex 3) and will not have an impact on the exposures as they facilitate part of the driver's tasks as turning on the wiper. For the noise, we only take into account the equivalent level, as the peak level is similar and below the limit value for both buses. We do not consider the vibrations of the rough road simulation as they represent only a small part of the road conditions in Switzerland, which are usually not used by buses. As only two buses on the twelve selected have been measured, the BEM might change as we realize that some characteristics are missing, or that some parameters need to be added.

6 Conclusion

Technological innovation in vehicle design and the energy strategy adopted in Switzerland, especially in the field of public transport, aim at improving the comfort and safety of vehicles and reducing pollution. These changes should be beneficial for the working conditions and occupational exposure of drivers. This hypothesis does not consider psychosocial factors. These will be studied in the second part of this project. It will provide a more global view of the working conditions of bus drivers.

To better characterize the different models that are part of the BEM, measurement campaigns are carried out to evaluate the different physical nuisances, but also those related to the ergonomics of the driving station. Although the BEM is based on the Swiss bus fleet, a large proportion of these vehicles are built and used abroad. It is therefore likely that other countries had similar technologies at the same periods. This would make it possible to represent the technological evolution of buses in Europe, among others, based on the typology of the Swiss fleet.

The inventory of the 315 bus models of the Swiss fleet allows us to extract a typology based on the technological characteristics of those vehicles. From the typology, we have chosen 12 representative buses to study. They correspond to the most widespread types of buses in Switzerland.

The first two measurement campaigns have shown an improvement in the working conditions of the bus drivers when they switched from the older model, the Volvo B58, to the Volvo B10M. The changeover reduced exposure to PM_{10}, noise and vibrations and improved the ergonomics of the workstation, especially from a visual point of view. However, the air change rate is lower for the Volvo B10M, which may be related to poorer air quality inside the bus.

The data collected during the two measurement campaigns is used to create the BEM. Subsequently, the BEM data will be used in an epidemiological study of Swiss bus and trolleybus drivers.

7 References

1. Norman, L.G., *The health of bus drivers: a study in London transport.* Lancet, 1958. **2**(7051): p. 807-12.
2. Lewis, C.A. and P.W. Johnson, *Whole-body vibration exposure in metropolitan bus drivers.* Occup Med (Lond), 2012. **62**(7): p. 519-24.
3. Kresal, F., et al., *Lower back pain and absenteeism among professional public transport drivers.* Int J Occup Saf Ergon, 2015. **21**(2): p. 166-72.
4. Yook, J.H., et al., *Cardiovascular disease risk differences between bus company employees and general workers according to the Korean National Health Insurance Data.* Ann Occup Environ Med, 2018. **30**: p. 32.
5. Bovio, N., D.B. Richardson, and I. Guseva Canu, *Sex-specific risks and trends in lung cancer mortality across occupations and economic activities in Switzerland (1990-2014).* Occup Environ Med, 2020.
6. Guseva Canu, I., et al., *Suicide mortality follow-up of the Swiss National Cohort (1990-2014): sex-specific risk estimates by occupational socio-economic group in working-age population.* Soc Psychiatry Psychiatr Epidemiol, 2019. **54**(12): p. 1483-1495.
7. Petersen, A., et al., *Cancer morbidity among Danish male urban bus drivers: A historical cohort study.* Am J Ind Med, 2010. **53**(7): p. 757-61.
8. Wu, W.T., et al., *Professional Driver's Job Stress and 8-year Risk of Cardiovascular Disease: The Taiwan Bus Driver Cohort Study.* Epidemiology, 2019. **30 Suppl 1**: p. S39-s47.
9. Netterstrom, B. and P. Suadicani, *Self-assessed job satisfaction and ischaemic heart disease mortality: A 10-year follow-up of urban bus drivers.* Int J Epidemiol 1993. **22**: p. 51–56.
10. Merlo, D.F., et al., *A historical mortality study among bus drivers and bus maintenance workers exposed to urban air pollutants in the city of Genoa, Italy.* Occup Environ Med, 2010. **67**(9): p. 611-9.
11. Vuchic, V.R., *Urban Transit Systems and Technology*. 2007, Hoboken, New Jersey: John Wiley & Sons, Inc
12. Black, J., *Urban Transport Planning. Theory and Practice*. 2 ed. 2020. 246.
13. Guseva Canu, I., et al., *Estimating historic exposures at the European Gaseous Diffusion plants.* Int J Hyg Environ Health, 2013. **216**(4): p. 499-507.
14. Guseva Canu, I., et al., *Development of a job exposure matrix for the epidemiological follow-up of workers in the French nuclear industry.* Revue d'Epidémiologie et de Santé Publique, 2008. **1**(56): p. 21-29
15. Gao, P., et al., *Assessment on the occupational exposure of urban public bus drivers to bioaccessible trace metals through resuspended fraction of settled bus dust.* Sci Total Environ, 2015. **508**: p. 37-45.
16. Chen, W.L., et al., *The impact of occupational psychological hazards and metabolic syndrome on the 8-year risk of cardiovascular diseases-A longitudinal study.* PLoS One, 2018. **13**(8): p. e0202977.
17. White, A.J., et al., *Air Pollution, Clustering of Particulate Matter Components, and Breast Cancer in the Sister Study: A U.S.-Wide Cohort.* Environ Health Perspect, 2019. **127**(10): p. 107002.
18. Schneider, E., *OSH in figures: Occupational safety and health in the transport sector — an overview*. 2011.
19. Kompier, M.A.J.D.M., Vittorio, *Review of bus drivers'occupational stress and stress prevention.* Stress Medicine, 1995. **11**: p. 253-262.
20. Lee, J.H. and H.B. Gak, *Effects of self stretching on pain and musculoskeletal symptom of bus drivers.* J Phys Ther Sci, 2014. **26**(12): p. 1911-4.
21. Yasobant, S., M. Chandran, and E. Reddy, *Are Bus Drivers at an Increased Risk for Developing Musculoskeletal Disorders? An Ergonomic Risk Assessment Study.* Journal of Ergonomics, 2015. **S3**: p. 1-5.
22. Golinko, V., et al., *Assessment of the Risks of Occupational Diseases of the Passenger Bus Drivers.* Safety and Health at Work, 2020. **11**(4): p. 543-549.
23. Celikhisar, H. and G.D. Ilkhan, *Association of presence and severity of obstructive Sleep Apnoea Syndrome with accident risk in city bus drivers.* J Pak Med Assoc, 2020. **70**(12(a)): p. 2184-2189.
24. Risco, J., et al., *Excessive sleepiness prevalence in public transportation drivers of a developing country.* Traffic Inj Prev, 2013. **14**(2): p. 145-9.
25. Deza-Becerra, F., et al., *Sleep habits, fatigue, and sleepiness in Chiclayo-Peru's bus drivers.* Sleep Breath, 2017. **21**(3): p. 745-749.
26. Anund, A., et al., *An on-road study of sleepiness in split shifts among city bus drivers.* Accid Anal Prev, 2018. **114**: p. 71-76.
27. Asaoka, S., et al., *Excessive daytime sleepiness among Japanese public transportation drivers engaged in shiftwork.* J Occup Environ Med, 2010. **52**(8): p. 813-8.

28. Tse, J., R. Flin, and K. Mearns, *Bus Driver Well-Being Review: 50 Years of Research.* Transportation Research Part F: Traffic Psychology and Behaviour, 2006. **9**: p. 89-114.
29. Jung, A. and H.C. Schuppe, *Influence of genital heat stress on semen quality in humans.* Andrologia, 2007. **39**(6): p. 203-15.
30. Valavanidis, A., et al., *Pulmonary oxidative stress, inflammation and cancer: respirable particulate matter, fibrous dusts and ozone as major causes of lung carcinogenesis through reactive oxygen species mechanisms.* Int J Environ Res Public Health, 2013. **10**(9): p. 3886-907.
31. Meier, R., et al., *Associations of short-term particle and noise exposures with markers of cardiovascular and respiratory health among highway maintenance workers.* Environ Health Perspect, 2014. **122**(7): p. 726-32.
32. Alizadeh, A., et al., *Noise-induced hearing loss in bus and truck drivers in Mazandaran province, 2011.* Int J Occup Saf Ergon, 2016. **22**(2): p. 193-8.
33. Pimenta, A.M. and A.A. Assuncao, *Thermal discomfort and hypertension in bus drivers and chargers in the metropolitan region of Belo Horizonte, Brazil.* Appl Ergon, 2015. **47**: p. 236-41.
34. Chiu, C.F., M.H. Chen, and F.H. Chang, *Carbon Dioxide Concentrations and Temperatures within Tour Buses under Real-Time Traffic Conditions.* PLoS One, 2015. **10**(4): p. e0125117.
35. Röösli, M., et al., *Systematic review on the health effects of exposure to radiofrequency electromagnetic fields from mobile phone base stations.* Bull World Health Organ, 2010. **88**(12): p. 887-896f.
36. Sagar, S., et al., *Radiofrequency electromagnetic field exposure in everyday microenvironments in Europe: A systematic literature review.* J Expo Sci Environ Epidemiol, 2018. **28**(2): p. 147-160.
37. Léman, A.R. *RétroBus Léman*. Available from: https://www.retrobus.ch/index.php?p=1.
38. publics, U.d.t. *VOV UTP*. Available from: https://www.voev.ch/fr/Bienvenue.
39. transports, S.d.p.d. *SEV*. Available from: https://sev-online.ch/fr/.
40. *MAVO SPOT 2 USB - Gossen.* Gossen, 2017.
41. AFNOR, *Principes d'ergonomie visuelle applicables à l'éclairage des lieux de travail*. 1990, Assocation française de normalisation (AFNOR): France. p. 34.
42. Guerry, E., et al., *Luminance Contrast Assessment for Elderly Visual Comfort Using Imaging Measurements.* Procedia Manufacturing, 2019. **32**: p. 474-479.
43. Suk, J.Y., *Luminance and vertical eye illuminance thresholds for occupants' visual comfort in daylit office environments.* Building and Environment, 2019. **148**: p. 107-115.
44. GART, U., *Confort des Postes de Conduites des Tramways*. 2015, GART, UTP: Paris, France. p. 44.
45. Griffin, M., et al., *Guide to good practice on whole-body vibration: non-binding guide to good practice for implementing Directive 2002/44/EC on the minimum health and safety requirements regarding the exposure of workers to the risks arising from physical agents (vibrations)*. 2006.
46. Cui, S., et al., *CO2 tracer gas concentration decay method for measuring air change rate.* Building and Environment, 2015. **84**: p. 162-169.
47. *Data sheet testo 435*. 2020; 8]. Available from: https://static-int.testo.com/media/fc/5d/da17bef960b7/testo-435-Data-sheet.pdf.
48. ANSI/ASHRAE, *ASHRAE STANDARD- Ventilation for Acceptable Indoor Air Quality*, in *ANSI/ASHRAE Standard 62-2001*. 2001, American Society of Heating, Refrigerating and Air-Conditioning Engineers, Inc: Atlanta, USA.
49. *8053B*. Narda; Available from: https://www.narda-sts.it/prodotti/misuratori/8053b/.
50. *Ordonnance sur la protection contre le rayonnement non ionisant (ORNI)*, in *814.710*, C.f. suisse, Editor. 1999: Switzerland. p. 24.
51. *personal/DataRAM™ pDR-1500 Aerosol Monitor*. Available from: https://www.thermofisher.com/order/catalog/product/PDR1500.
52. Ofev, O.f.d.l.e. *Cartes des valeurs quotidiennes*. Available from: https://www.bafu.admin.ch/bafu/fr/home/themen/thema-luft/luft--daten--indikatoren-und-karten/luftbelastung--daten/luftbelastung--historische-daten/film--ozonmaximum.html.
53. *Ordonnance du 16 décembre 1985 sur la protection de l'air (OPair)*, C. fédéral, Editor. 1985: Switzerland.
54. Kjaer, B. *Technical documentation - Noise dosimeter type 4448*. [cited 2021; Available from: https://www.bksv.com/-/media/literature/Product-Data/bp2420.ashx.
55. Kjaer, B. *Technical documentation - Noise dosimeter type 4445*. Available from: https://www.bksv.com/media/doc/bp2106.pdf.

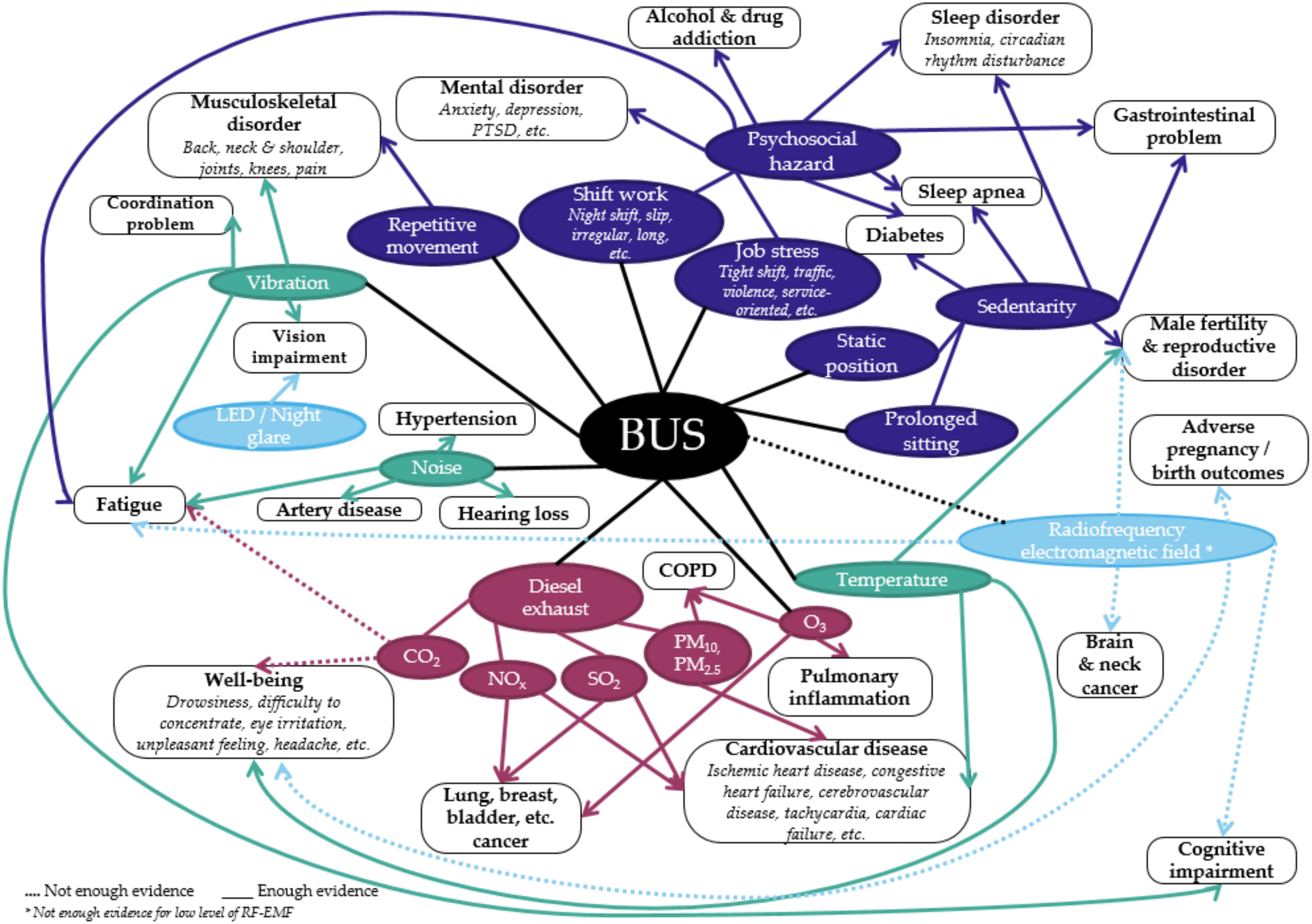
56. SUVA, *Valeurs limites d'exposition aux postes de travail*, in *1903.f*, S.-P.d.l.s.-D.m.d. travail, Editor. 2021, SUVA: Switzerland. p. 60.
57. Norsonic. *Product data: 3 channel Vibration Meter Nor 133, 6 channel Vibration Analyser Nor 136, NorVibraTest PC application program Nor 1038*. Available from: https://web2.norsonic.com/wp-content/uploads/2021/12/PD-133_136-Ed3Rev4En-1221.pdf.
58. Norsonic. *Product Data, Vibration transducers and accessories Nor1270/Nor1271/Nor1286/Nor1288*. Available from: https://web2.norsonic.com/wp-content/uploads/2021/03/PD-VibTrans-Ed2Rev1-Eng-0416.pdf.
59. Adam, S.A. and N.A.A. Jalil, *Vertical Suspension Seat Transmissibility and SEAT Values for Seated Person Exposed to Whole-body Vibration in Agricultural Tractor Preliminary Study*. Procedia Engineering, 2017. **170**: p. 435-442.
60. FLIR, T. *Compact Thermal Camera FLIR C5*. Available from: https://www.flir.com/products/c5/.
61. *Murphy's law*, in *Wikipedia*. 2021.
62. medev, *agrometeo.* agrometeo.
63. *Register IVZ-Fahrzeuge*. 2021, Eidgenössisches Departement für Umwelt, Verkehr, Energie und Kommunikation UVEK.
64. Services, M. *Typenscheine*. Available from: https://typenscheine.ch/fr.
65. Jalilian, H., et al., *Public exposure to radiofrequency electromagnetic fields in everyday microenvironments: An updated systematic review for Europe.* Environ Res, 2019. **176**: p. 108517.

8 Annexes

8.1 Annex 1: Mind map of the health issues of bus drivers and their causes

Due to its size, the mind map is represented on the next page

Figure 23: Mind map of the health issues affecting bus drivers and their causes



BUS
Psychosocial hazard
Shift work
Night shift, slip, irregular, long, etc.
Job stress
Tight shift, traffic, violence, service-oriented, etc.
Repetitive movement
Sedentarity
Static position
Prolonged sitting
Vibration
Noise
Temperature
LED / Night glare
Radiofrequency electromagnetic field *
Diesel exhaust
CO_2
NO_x
SO_2
PM_{10}, $PM_{2.5}$
O_3
Alcohol & drug addiction
Sleep disorder
Insomnia, circadian rhythm disturbance
Mental disorder
Anxiety, depression, PTSD, etc.
Gastrointestinal problem
Musculoskeletal disorder
Back, neck & shoulder, joints, knees, pain
Sleep apnea
Diabetes
Coordination problem
Vision impairment
Male fertility & reproductive disorder
Hypertension
Adverse pregnancy / birth outcomes
Fatigue
Artery disease
Hearing loss
COPD
Brain & neck cancer
Pulmonary inflammation
Well-being
Drowsiness, difficulty to concentrate, eye irritation, unpleasant feeling, headache, etc.
Cardiovascular disease
Ischemic heart disease, congestive heart failure, cerebrovascular disease, tachycardia, cardiac failure, etc.
Lung, breast, bladder, etc. cancer
Cognitive impairment
.... Not enough evidence
____ Enough evidence
* Not enough evidence for low level of RF-EMF

8.2 Annex 2: Questionnaire for ergonomic parameters

Table 15: Questionnaire for the study of the different ergonomic parameters of bus driver's workplace. It includes biomechanical parameters and visual parameters

Parameters	**Yes**	**No**	**Comments / Values**
Seat			
Number of adjustable functions			
Vertical adjustment > 10 cm			
Front and back adjustment > 15 cm			
Back rest tilt adjustment between 90° and 120°			
Seat tilt adjustment: 5°±5° (recommended 10°)			
Seat length adjustment 39-50 cm			
Curved lumbar support			
Lumbar support adjustable in height			
Lumbar support adjustable in thickness±2cm, thickness between 3 and 5 cm			
Headrest height >86 cm			
Height of headrest if disjoint > 12 cm			
Backrest height >50 cm (optimal >60 cm)			
Easy to use controls for adjustment			
Type of shock absorber			
Weight adjustment of shock absorber: 45-130 kg			
Steering wheel			
Diameter < 50 cm			
Adjustable in height			
Forward and backward adjustment			
Tilt angle adjustment of 15-32° from vertical			
Elbow are on the side during the 9h-3h position			
Pedals			
Equal angles			
The range of angles < 25 °			
Reachable by small drivers			
Dashboard			
* Uniform design by categories (e.g., warning)			
Easy access →radius >60 cm for each arm			
* Intuitive (lights and symbols, etc.)			
* Easy to read, easily visible			
* Clear and distinct colors			
Workplace			
Sufficient space: cabin height> 2 00 cm, legroom > 50 cm			

Efficient and adjustable (direction, intensity) heating system			
Efficient and adjustable (direction, intensity) cooling system			
Access to the driver’s cab: width > 55 cm, height > 1 90 cm			
Other equipment reachable without excessive bending (<15° lateral or profile)			
Other equipment reachable without twisting of lower back			
SCORES	# of yes		Maximum possible
Global			32 or 33 if disjoint headrest
Visual (*)			6 (with contrast)
Biomechanics			26

Dashboard includes turn signal, windshield wiper, horn, safety brake, door opening, etc.

Other equipment includes on-board sale device, radio, microphone, ventilation, etc.

8.3 Annex 3: Complete list of the attributes characterizing a bus model

1) Model
2) Type of bus
3) Building year
4) Manufacturer
5) First year in service
6) Years in service-start
7) Years in service –end
8) Length [m]
9) Width [m]
10) Height [m]
11) Tare weight [kg]
12) Full load weight [kg]
13) Capacity (number of persons)
14) Existence of a trailer [yes/no]
15) Number of joint
16) Transmission
17) Gearbox
18) Number of cylinders
19) Power of the engine
20) Details of the engine
21) Euro standard
22) Engine position
23) Suspension [type]
24) Power steering [type]
25) Electronic stability control [yes/no]
26) Preventive emergency braking assistance [yes/no]
27) Active/Adaptive cruise control [yes/no]
28) Active electric assistance [yes/no]
29) Light sensor with light control [yes/no]
30) Rain sensor with wiper control [yes/no]
31) Heated windshield [yes/no]
32) Automatic tire pressure control [yes/no]
33) Rear view camera [yes/no]
34) Automatic passenger counting [yes/no]
35) On-board sales [yes/no]
36) Anti-aggression/COVID protection (type)
37) Customer information system (type)
38) Air conditioning [yes/no]
39) Heating (type)
40) Soundproofing (type)
41) ABS and other brake aids [yes/no, complement]
42) Other characteristic equipment
43) Comfort elements for the driver
44) Driver's seat
45) Element of discomfort for the driver
46) Low floor [yes/no]
47) Hydrocarbon [mg/km]
48) CO [mg/km]
49) NOx [mg/km]
50) HC+NOX [mg/km]
51) PM [mg/km]
52) Evaporation [mg/km]

8.4 Annex 4: Temporal evolution of buses

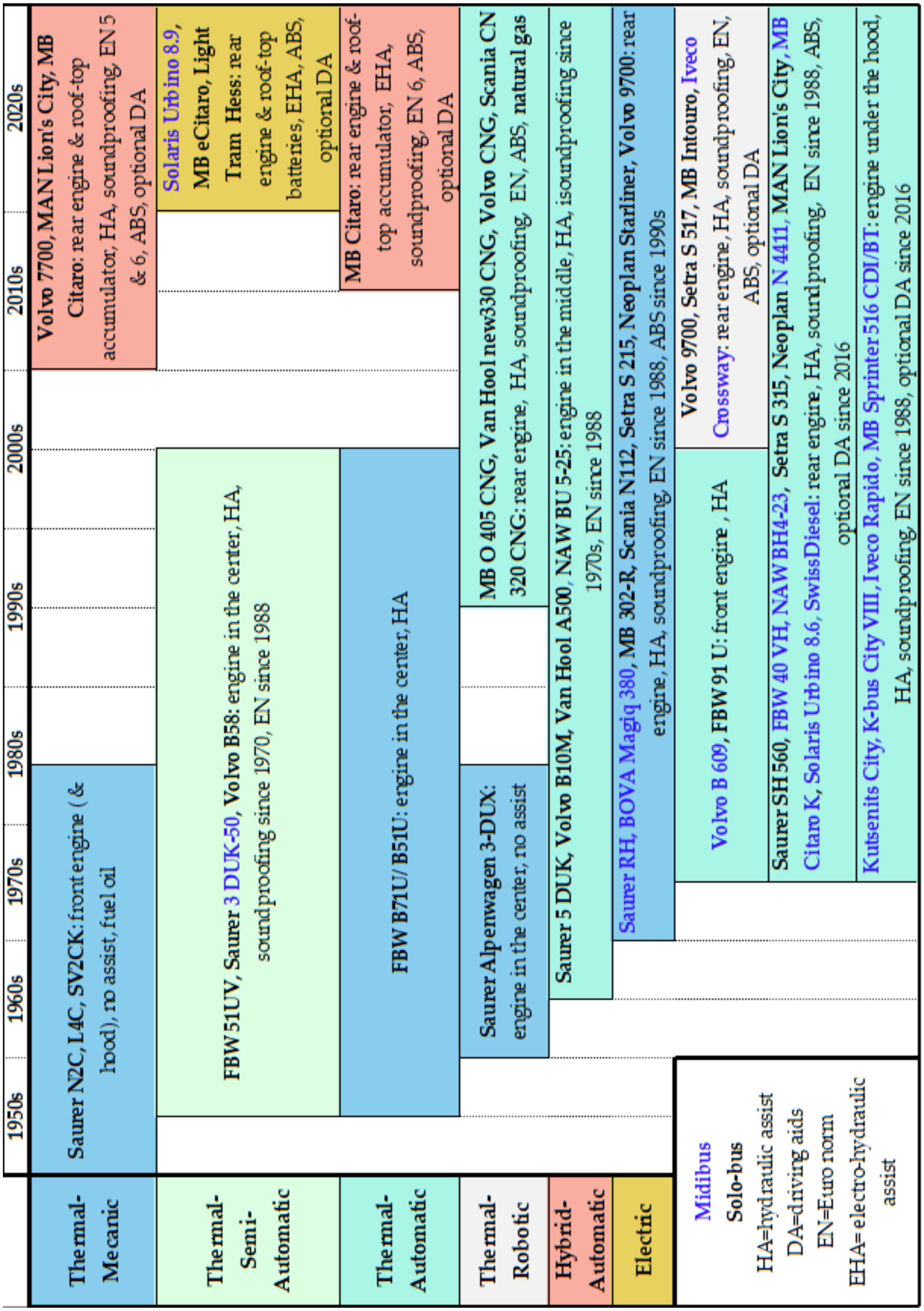


Figure 24: Temporal evolution of bus typology in Switzerland since 1950

8.5 Annex 5: Map of the urban simulation

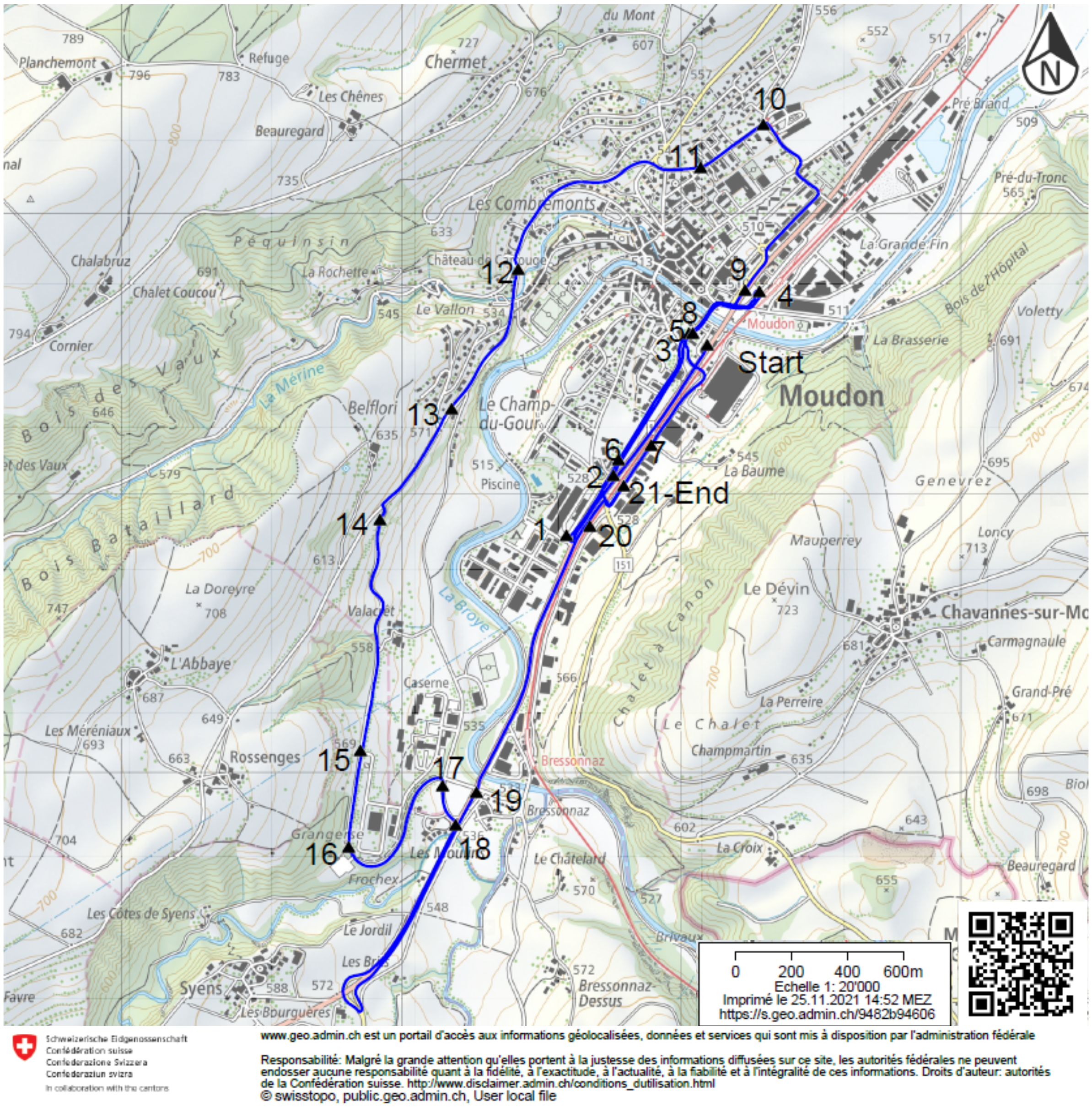


Figure 25: Map of the urban simulation with indication of the stops. (*https://s.geo.admin.ch/9482b94606*)

8.6 Annex 6: Map of the regional simulations

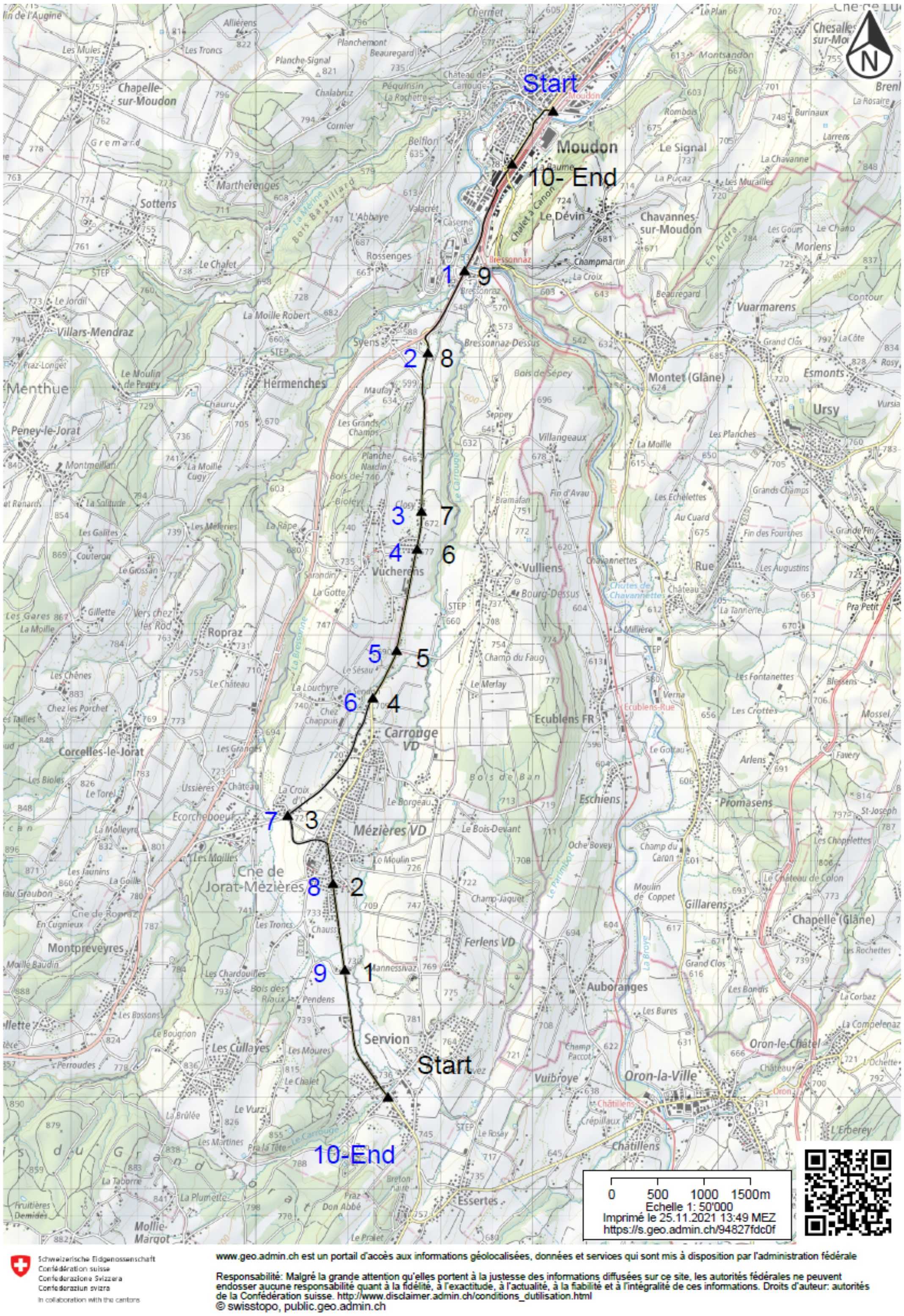


Figure 26: Map of the regional simulations with indication of the stops. In blue is the trip 1 and in black the trip 2 (*https://s.geo.admin.ch/94827fdc0f*)