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Analysis of the Impact of the Comfort Systems in Sport Utility Vehicles on the Exhaust Emissions Measured under Worldwide Harmonized Light Vehicles Test Cycles Conditions

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ABSTRACT

This study investigated the impact of comfort systems in sport utility vehicles (SUVs) on exhaust emissions and fuel consumption under the worldwide harmonized light vehicles test cycle (WLTC) conditions. Two modern SUVs equipped with gasoline engines of 3.6 and 2.0 liter displacement were tested, both featuring various comfort systems, such as automatic climate control, heated seats, and active safety systems. Measurements were conducted using a chassis dynamometer under three operating modes: with comfort systems off, with comfort systems on, and with comfort systems on in sport mode. The results indicated that the activation of comfort systems leads to significant increases in fuel consumption and emissions, including hydrocarbons (up to 29%), carbon monoxide (up to 42%), and particulate matter (up to 58%). The study highlighted the necessity of conducting further research on the influence of comfort systems on vehicle emissions, particularly as these systems become more prevalent in modern vehicles. Additionally, the research underscored the potential for increased operational costs and environmental impact due to enhanced vehicle comfort features.

Keywords: fuel consumption, exhaust emission, WLTC, comfort systems.

INTRODUCTION

Vehicle transport is gaining increased popularity among the members of modern society and vehicles are becoming more accessible to the average user. The time spent in transit is growing too [7, 18, 29]. The choice of a car as the basic means of transport is predominantly dictated by its advantages: direct relocation (independent from the destination), advanced road infrastructure, low traveling and maintenance costs and increased comfort compared to other transport modes [8, 10, 12]. It is noteworthy that increased accessibility to vehicles is predominantly caused by a well-developed market of preowned vehicles of much reduced pricing. Used vehicles tend to have higher basic fuel consumption, but also fewer comfort systems [2, 7]. Particularly for vehicles homologated with the NEDC cycle in the EU, the difference between the assumed level of emissions and their actual environmental impact as studies have shown can be significant [1, 3–6, 13, 60, 61]. An additional problem is the continued increase in the number of passenger vehicles operating on the roads. Exclusively in Poland, the years 2015–2020 have seen a 21% increase in the number of passenger vehicles. Eventually, the number of passenger vehicles in the said period reached over 25,113.000. This growth exceeding 20% placed Poland in the 4th position among the EU members with the highest increment of passenger vehicles [8]. Similar trends can be observed in the entire European Union. According to the Eurostat data, the number of vehicles grows annually. In 2020, a 13% increase in the number of passenger vehicles was recorded compared to 2015 [2]. Even a tidal wave of new vehicles may make relatively little difference to the emissions from the vehicle fleet, especially since a lot of them are in poor condition, but the problem is important for improving air quality, especially in cities [59].

Contemporary vehicles offer a wide variety of driver's preference adaptations. The list of stock equipment in terms of safety grows increasingly through introductions of subsequent standards enlarging the list of mandatory equipment (safety and comfort systems) [7, 10, 13, 14]. In terms of comfort, one may observe not only the growing number of features, but also a transfer of technology from high-end vehicles to lower vehicle segments, though with limited functionalities (reduction of the maximum active cruise control speed or no traffic jam assist). The systems that were a novelty in luxury vehicles a few years ago are now an option in compact vehicles and are seeing their development and the addition of new systems [12]. All solutions aiming at the improvement of the comfort and safety (both passive and active) usually result in increased vehicle weight caused by fitting of additional components. This is one of the factors that directly affects the resistance forces of a vehicle in motion [15, 16].

Additional systems significantly impact the weight of the vehicle. The weight is already substantial in vehicles of the premium sector, owing to the application of large displacement high-power engines. The multitude of applied systems increases the weight of a vehicle by up to 100 kg but, most importantly, increases the electric energy demand [7, 12, 17]. The highest instantaneous power demand of energy receivers is attributed to the vehicle climate control (heating or cooling) [13, 43, 58]. The advancement of active safety systems such as blind spot monitoring, pedestrian automatic emergency braking or collision alerts is also becoming a trend [14, 45, 54]. The technologies related to safety systems are continuously evolving owing to technological advancement and installation of additional components such as cameras, radar detectors, lidars and ultrasonic sensors [17].

The advancement of autonomous vehicles additionally boosts the progress of the safety system technology in such solutions as advanced warning systems and systems of collision avoidance. In the future, greater automation of the comfort functions such as seat, climate or light personalization features may be expected. In terms of driver's comfort and safety improvement, such systems as health condition monitoring are expected (pulse and stress level). Another opportunity is the employment of artificial intelligence and machine learning in boosting the already advanced systems of collision prediction and avoidance [17, 40]. The integration of comfort and safety systems with the infotainment systems is also becoming a trend. This allows the access to real-time traffic information, satnav and audio through a single interface. The increase in the significance of the vehicle-to-vehicle (V2V) and vehicle-to-infrastructure (V2I) communication will enable exchange of information between vehicles and road infrastructure to increase safety and comfort. The performed analysis confirms that these systems are already fitted in vehicles on a reasonable scale and their presence will continue to grow. The fitting of the systems increases the weight, but most importantly, exerts additional load on the engine, which may substantially impact the actual exhaust emission [21, 27, 44]. A significant number of operated vehicles facing the mentioned issue can potentially lead to a substantial increase in emissions from the passenger car (PC) sector compared to homologation data. Moreover, as the number of systems grows, this could further contribute to the ongoing trend of pollution escalation.

The authors in their previous works confirmed an increase in fuel consumption during real driving emissions (RDE) tests compared to type approval tests [19, 44, 47, 63]. However, the impact of comfort devices at most different driving modes was not studied. The literature analysis did not reveal any sources that showed empirical measurement of increased toxic emissions from individual vehicles. Most sources have indicated that air quality deterioration due to vehicle use has occurred, mainly by running computer simulations [44, 62]. In another publication [36], the authors of this paper showed that traffic intensity has minimal impact on local air quality, mainly due to weather conditions and significant low-level emissions in the vicinity.

There is not much research in the scientific literature on ensuring thermal comfort in car cabins. In one of the analyzed publications, the authors conducted a survey on how air conditioning modes were used by its users. The majority of respondents (57%) use a recirculation mode, which is beneficial from the point of view of energy demand for the air preparation process. However, users do not realize that recirculation causes an increase in CO_2 concentration, which can negatively affect the perception of the driver [23, 26, 61]. In article [37] authors raised the important topic of lack of awareness regarding the need to ventilate enclosed spaces. The processes of preparing and exchanging air from enclosed spaces require the supply of energy and taking into account issues related to the quality of indoor and outdoor air as well as location [48, 49, 58]. Important parameters are PM2.5 and CO_2 concentration [8, 9]. Therefore, appropriate control strategies for ventilation in car cabin are needed [10]. In the case of vehicles, this is mainly at the expense of fuel [7, 59]. However, this topic is not widely studied. The authors of one of the articles conducted research on air quality in the cabins of two different cars [11]. These measurements made it possible to assess the variability of the concentrations of various pollutants when vehicles were fueled with different types of fuels. The influence of the type of engine on the quality of air parameters in the cabin was noticed. The authors did not take into account fuel consumption in the tests.

Others explored new system solutions that can ensure the regulation of air parameters in the cabin in the range of 21–23 °C and relative humidity in the range of 40–50%, which is a good indicator of thermal comfort [53]. Incorrect relative humidity ranges can cause dry eyes and skin, which is associated with the use of air conditioning [22]. Other authors have investigated the effect of cabin temperature and vehicle placement in sun and shade on comfort sensations, suggesting that car air conditioning is needed [32, 42]. These studies also did not take fuel consumption into account. Authors of [22], came to a similar conclusion that assessing cabin temperature has the greatest impact on the feelings of comfort and discomfort by drivers.

However, there are studies in which relative humidity is modeled [25]. Owing to the model, it would be possible to control the ventilation of the car cabin as a function of increasing relative humidity, the source of which is the breathing of passengers. However, in the first stage of the study, the authors analyzed only two cars and did not analyze fuel consumption. Extending the analysis, however, it was estimated that fuel consumption will be higher by 6% when using cooling [24]. Other authors who studied fuel consumption while assessing the impact of cabin temperature consumption assessed that a properly configured AC system is able to work in such a way that fuel consumption is low. However, they adjusted the air conditioning at 25.2–26.2 °C, which seems a bit too high as for the thermal comfort. In addition, they did not work on the typical AC system used in vehicles, and its use would require structural changes [7]. Another type of comfort improvement system can be heated/water-cooled seats, providing the passengers with higher driving comfort [39]. Although some referenced research regarding thermal comfort in car cabin they did not take into account fuel consumption or pollutant emissions while providing thermal comfort. This is a research gap that was bridged in with the described research.

For the aforementioned reasons, the authors decided to conduct tests of toxic emissions from the exhaust system under controlled and similar operating conditions, with different powertrain conditions and with the use of comfort systems. The research conducted in this article was aimed at determining whether comfort systems significantly contribute to an increase in toxic exhaust emissions and fuel consumption. SUVs were chosen for the study, firstly because of their growing popularity in offerings and sales, as well as the multitude of comfort systems that can be implemented in them. In addition, more modern designs often use soft or mild hybrid systems, which can affect the results of the article described in a study of two SUVs specifically tested on a dedicated approval cycle to obtain repeatable measurements. For this reason, the vehicles tested were equipped with a conventional modern gasoline engine.

MATERIALS AND METHODS

Research objects

In the homologation procedure, passenger vehicles (PC) undergo measurements on a chassis dynamometer. The cycle aims at reproducing the drive under actual traffic conditions. Multiple research works confirmed that these types of tests reproduce the local traffic conditions only to a limited extent [32, 42]. Still, the authors applied this type of test in this work due to its high measurement repeatability, which does not occur in the tests performed in real-world conditions [2, 3, 8, 15, 41]. Approval tests have a number of restrictions on the conditions for measuring the preparation of the car as well as the equipment used by guaranteeing the repeatability and reliability of the results obtained. The measurements of the exhaust emissions were carried out on a chassis dynamometer under controlled, homologation-specified conditions. Approval assumptions primarily assume specific physical conditions, including pressure and temperature. In addition, all instruments used must be certified, and exhaust gas analyzers must be calibrated as well as zeroed in ambient air before measurements. The authors reproduced the WLTC test. The tests were completed at a certified testing center BOSMAL in Bielsko-Biała in accordance with the requirements set forth in the Euro emission standards. The NEDC cycle was replaced by the WLTC cycle in 2017, which has made it possible to better reflect the actual driving conditions of passenger vehicles.

The investigated objects were two SUV vehicles fitted with gasoline engines of different displacement, i.e. 3.6 dm^3 and 2.0 dm^3, and similar equipment. Comfort features included heated and ventilated front seats and heated rear seats, automatic three-zone climate control, radar and active cruise control, heated mirrors and steering wheel, and a premium multi-speaker sound system. In order to preserve clarity, in further parts of the paper the vehicles are referred to as Vehicle 1 and Vehicle 2 (Figure 1).

The engines of the tested vehicles are modern, turbocharged units that, depending on the work point, operate on 1, 2 or 3 fuel doses per cycle. A greater number of fuel doses is used when the engine operates under 2000 RPM and under high loads. The aftertreatment system is composed of two catalytic converters: a ceramic TWC contained in a single metal casing. For Vehicle 1, due to the V engine cylinder arrangement, this system is doubled. The vehicles were not originally fitted with particulate filters. The engine has a feature of engine cooling governed by the vehicle ECU and a function of energy recovery through the generator during engine braking. The vehicles had mileage readings under 1000 km. The mileage of the cars meant that they were after the first service, which allows concluding that the vehicles are in working order and free from possible factory defects. Detailed specifications have been presented in Table 1. The technical data of the vehicles enables

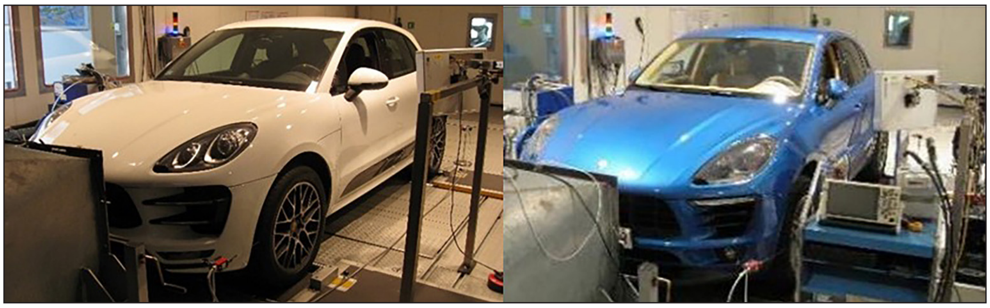

Figure 1. Vehicles during the tests (a) Vehicle 1 (b) Vehicle 2

Table 1. Technical specifications of Vehicle 1 and Vehicle 2

Parameter	Vehicle 1	Vehicle 2
Ignition/fuel type	Positive ignition/gasoline	
Displacement [dm^3]	3.6	2.0
Number and arrangement of cylinders / number of valves	V-type, 6/24	Straight, 4/16
Supercharging	2 biturbo turbochargers	Twin scroll turbocharger
Compression ratio	10.5:1	9.6:1
Maximum power output	294 kW at 6000 rpm	180 kW at 5000 rpm
Maximum torque	550 Nm at 1350-4500 rpm	400 Nm at 1800-4500 rpm
Aftertreatment	two TWC, one per each bank	one TWC
Emission standard	Euro 6	
Drivetrain	Full-time 4WD	
Transmission	Dual clutch 7 speed automatic,	
Curb weight	1945 kg	1887 kg

direct comparison with each other in terms of fuel consumption and toxic emissions with simultaneous verification of results for engines of different displacement and horsepower.

Measurement equipment

The measurements were conducted on the same day at the ambient temperature and pressure of 24 °C and 980 hPa for Vehicle 1 and 20 °C and 984 hPa for Vehicle 2, respectively. This information is crucial because ambient conditions, including the air quality, may affect the measurements, particularly if they are of comparative nature. The specifications of the measurement equipment have been presented in Table 2 and the specifications of the chassis dynamometer in Table 3. Figures 2–4 present the measurement equipment and the dynamometer. These are certified devices that can be used for emissivity measurements in homologation tests.

The measurement was carried out in three cycles depending on the driving modes and use of the comfort systems. Each time before the test, the drivetrain was brought up to temperature i.e., a single run of the homologation cycle was performed after a cold start (Figure 5). As a result, the following drivetrain states were tested:

- drivetrain up to temperature – the test run starts when the engine reaches its operating temperature (coolant and engine lubricant), after one entire NEDC cycle – named "without systems",
- drivetrain up to temperature, comfort systems active – as above plus all available vehicle comfort systems activated, named "with systems",
- drivetrain up to temperature comfort systems active, drivetrain in the sport mode – as above plus sport mode activated, named "with systems sport mode".

The activation of the comfort systems is to be understood as: air conditioning on temperature setting 20 degrees Celsius, auto mode, mirror

Figure 2. The equipment used for the measurements Horiba 7000 NT analyzer

Figure 3. The equipment used for the measurements – AVL Dyno 48 4 × 4 chassis dynamometer

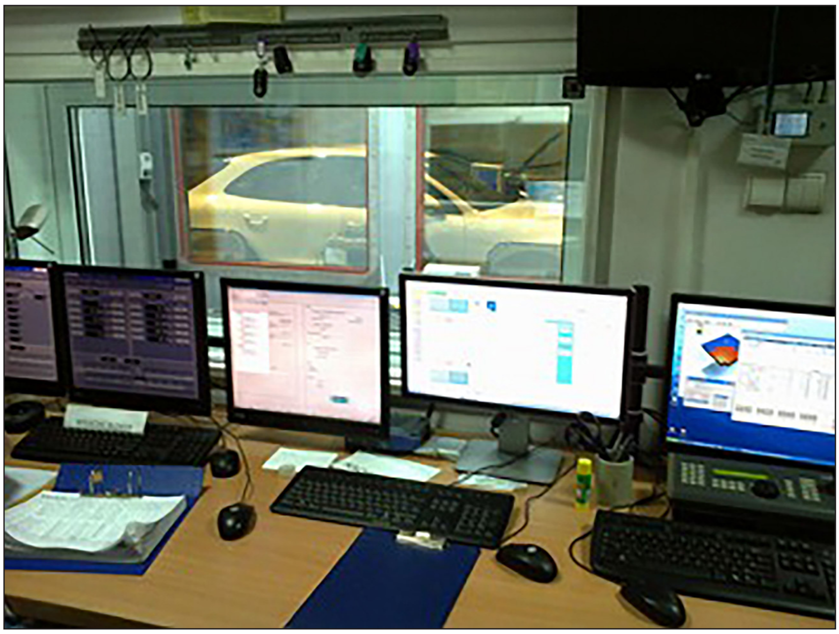

Figure 4. Vehicle during the test on the chassis dynamometer

defrost on, front seat ventilation on, rear seats and steering wheel heating on, FM audio on (volume at 50%). The sport mode maintains higher engine speed, faster gearshifts and improved sensitivity of the acceleration pedal to the driver's command. According to the engine efficiency theory, in such a case the said efficiency should drop [16]. During the tests, ambient air quality was tested as well to consider this parameter when measuring the concentration of the exhaust components.

Table 2. Emissions analyzers data

Parameter	Measurement method	Measurement range
NO_x (lower measurement range)	CLD	0–5/5000 ppm (dual range)
NO_x	NDIR	0–200/5000 ppm (dual range)
SO_2 (lower measurement range)	NDUV	0–10/1000 or 0–5/1000 ppm
SO_2	NDIR	0–200/5000 ppm (dual range)
CO (lower measurement range)	NDIR	0–5/500 ppm (dual range)
CO	NDIR	0–100/5000 ppm (dual range)
CO (upper measurement range)	NDIR	0–5% of the volume
CO_2	NDIR	0–5/50% of the volume
PM	Photoacoustic	0.001–150 mg/m^3
PN	Spectrometer	5.6–560 nm

Table 3. AVL Dyno 48 4× 4 chassis dynamometer data

Specifications	Value
Repeatability	±0.5% full scale; ±0.1% full scale (extended range)
Communication	RS-232C, RS-485
Communication ports	USB, Ethernet
Ambient temperature	Standard: 5–40°C, optional: -5–50°C
Response time	45 sec. (maximum value at the input (T_{90})
Maximum measurement deviation	±2.0% of the entire range
Dimensions [mm]	651x813x1905
Weight	Approx. 318 kg.

Figure 5. Exhaust gas uptake system during the test on the chassis dynamometer

RESULTS

Exhaust components under analysis were hydrocarbons. This is a group that includes over 200 different compounds [35]. All THC (total hydrocarbons) and NMHC (non-methane hydrocarbons) were investigated during the tests, as prescribed in the standard. Methane is treated as practically neutral for the natural environment [27]. The authors also measured: carbon dioxide, carbon monoxide, nitrogen oxides and particulate matter (PN). The results were divided in terms of the investigated objects and the analysis was performed against the emission obtained for the vehicles with the comfort systems off (systems off).

The results have been presented in Tables 4 and 5. They were averaged for the entire test, even though the chassis dynamometer results were divided into urban and rural cycles, as well as the weighted average (rural cycle). Using the carbon balance method, fuel consumption is determined from these emissions, as presented by the manufacturers in their advertising folders [47].

In order to facilitate the interpretation of the comparative tests results regarding individual exhaust components and fuel consumption, the test run no. 1 was completed with the comfort systems off as a reference and marked 100% on the graphs, which makes subsequent references to the obtained results relative in the further part of the paper. When analyzing the results of Vehicle 1 (Figure 6), it may be observed that activating the comfort systems increased the exhaust emissions of all exhaust components from 22% to 58%.

The greatest increase was observed for the emission of PM (58%). Also, great increase of the

Table 4. Exhaust emissions from Vehicle 1 vs state of the drivetrain

Emissions vs vehicle state	THC [mg/km]	CO [mg/km]	NO_x [mg/km]	CO_2 [g/km]	PN [#/km]	PM [mg/km]
Up to temp	37.0	196	14.7	214	9.10E+11	1.04
Up to temp, comfort systems on	47.7	241	20.7	233	1.30E+12	1.64
Up to temp, sport mode on, comfort systems on	48.5	329	34.7	347	1.11E+12	1.48

Table 5. Exhaust emissions from Vehicle 2 vs state of the drivetrain

Emissions vs vehicle state	THC [mg/km]	CO [mg/km]	NO_x [mg/km]	CO_2 [g/km]	PN [#/km]	PM [mg/km]
Up to temp	98	72	110	266	1.17E+12	3.12
Up to temp, comfort systems on	121	89	103	330	1.23E+12	3.18
Up to temp, sport mode on, comfort systems on	102	75	109	356	1.83E+12	4.40

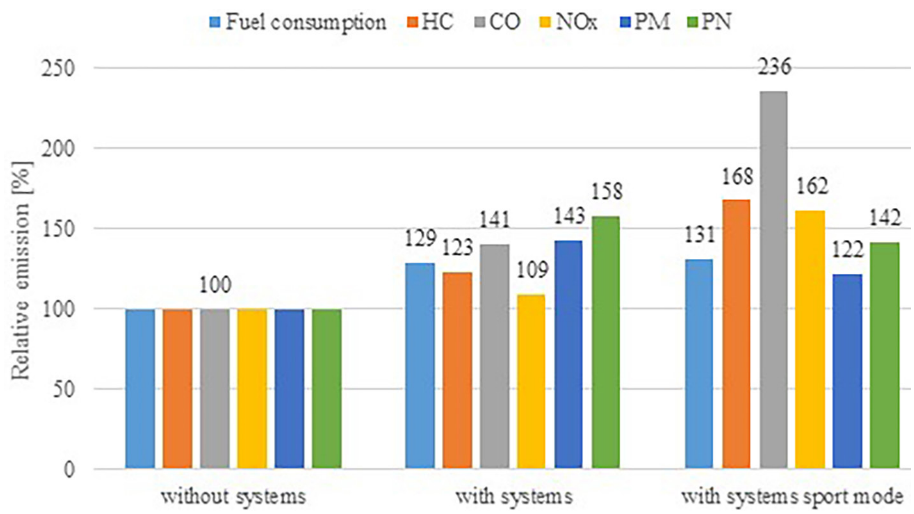

Figure 6. Vehicle 1 relative emissions in the WLTC cycle

exhaust emission occurred for Particle Number (43%) and nitrogen oxides (41%), then came HC and CO with a 29% and 23% increase, respectively. It is noteworthy that the activation of the said comfort systems additionally caused increased fuel consumption (9%). PM has grown in a different way, increasing emissions when the systems are turned on and in sport mode %, after the graph does not show the union emissions of PM and PN. The activation of the sport mode had a far more inconclusive impact on the exhaust emissions. In the case of this vehicle state, a high increase in the emission of nitrogen oxides (136%) was observed. A higher emission was also observed for hydrocarbons and carbon monoxide. When comparing the results for the test runs with all the systems off, the emission was greater by 31% and 68%, respectively. The fuel consumption increased significantly by 62%. PM and PN raises less, by 42% and 22%, respectively. These results are higher compared to the state when the sport mode was off. Interestingly, the activation of the sport mode in the WLTC cycle reduced the emission of PM by approx. 16% and PM by 21%. This parameter is of exceptional significance, as it has been confirmed that small particles are extremely hazardous to human health. The reduction of the PN emission may be the effect of intensification of the exhaust oxidation processes following the increased temperature in the aftertreatment systems (due to the higher fuel consumption).

A similar analysis was performed for Vehicle 2. In the case of this research object, the use of the comfort systems increased the emission of hydrocarbons (23%) and carbon monoxide (42%) (Figure 7). The emission of nitrogen oxides was reduced by 6%. PM and PN increased by only 2% and 7%, respectively. It is noteworthy that the

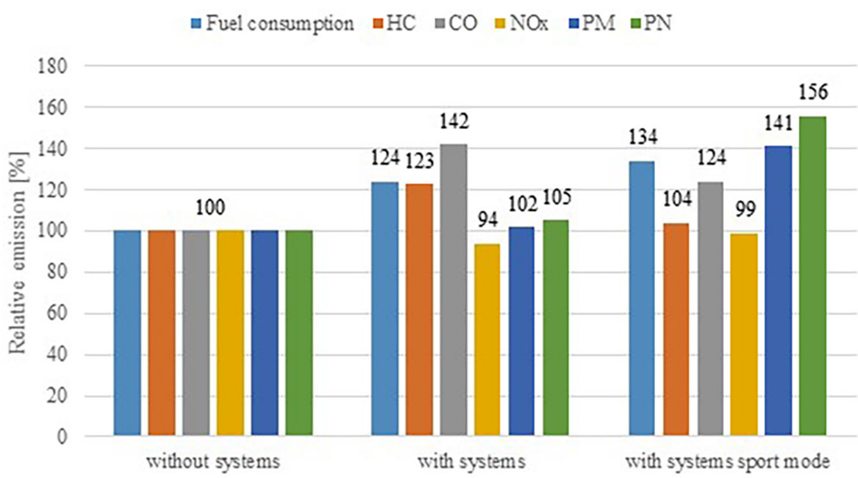

Figure 7. Vehicle 2 relative emissions in the WLTC cycle

activation of the comfort systems resulted in an increase in the fuel consumption of as much as 24%. For Vehicle 1, this value is 5 percent points higher, at which the engine of Vehicle 2 had a reduced maximum power output. The results of Vehicle 2 in the tests performed with the comfort systems and sport mode on vary significantly from those obtained for Vehicle 1. In this case, a 4% increase of the emission of hydrocarbons and a 1% reduction of the emission of nitrogen oxides were observed. The emission of carbon monoxide increased (24%) along with the emission of particle mass (41%) and number (56%). During this test, the fuel consumption grew by 34%. This value, however, was higher by 3 percent points from the value obtained for Vehicle 1, fitted with an engine of higher displacement. The obtained changes are different for the two vehicles and it is hard to find similarities in the detailed results.

DISCUSSION

The studies conducted so far by the authors have presented a similar approach to the problem, but they focused on measurements of passenger cars (PC) under real-world conditions, not necessarily carried out according to the RDE guidelines [39]. Due to this reason, a decision was made to conduct measurements under repeatable conditions, where the WLTC test showed a clear influence of vehicle systems. However, this influence is ambiguous and requires detailed research on a single vehicle in various drive states. This will allow for a better determination of the usage of comfort systems in vehicles.

Due to the fact that the time spent in vehicles is usually long, drivers would like to spend it comfortably. This comfort should be maintained regardless of the season. Therefore, in summer, air conditioning and cabin cooling should be used [32, 42], while in winter air should be heated [53]. As the literature review showed, it is also necessary to take into account the ventilation of the cabin, i.e. air exchange [37], to ensure proper air quality conditions, i.e. low CO_2 concentration to improve the driver's perception [23, 26]. However, the use of vehicle equipment in such a way as to maintain appropriate conditions in the cabin may be associated with an increase in pollutant emissions to the atmosphere. Taking into account the fact that the particulate matter from transport worsens air quality [3, 35, 40, 46, 50, 55], efforts should be made to one should strive not to generate increased air pollution using all amenities [51]. The results of the conducted research have inconclusively indicated whether the use of comfort systems increases pollutant emissions. In some modes and within certain pollutants, there has been an increase in pollution and in others a decrease. This requires further research.

From the drivers' point of view, reducing fuel consumption should also be an equally important aspect. It is generally known that the use of amenities aimed at improving thermal comfort is associated with incurring additional energy expenditures which is the case, for example, with buildings [28, 30]. However, the scientific works devoted to fuel consumption while ensuring comfort in the cabin are rare, present in [7]. Recently, the trend is to use the solutions that are local and personalized, owing to which the demand for energy is reduced [20]. This also applies to cars [39, 53]. Their introduction would require the redesign of cars, which, despite favorable research results, may not be feasible.

The research results presented in the article showed that indeed the use of additional comfort systems resulted in an increase in fuel consumption by 24% to 29%. It can be clearly stated that using comfort systems increases fuel consumption by 6% to 20%, which is also the value obtained by other researchers [24]. With Sport mode, fuel consumption has increased even more – by 31% and 34%. These results can be used to increase user awareness that the way hardware capabilities are used is associated with increased operating costs.

The presented research aimed to show that the use of comfort systems can generate pollution and increase fuel consumption. On the basis of the published papers, it was assumed that the research would take place in one day, because the temperature of the outdoor air affects the systems that provide comfort [22]. The air conditioning was set to a temperature of 20 °C, which is lower than the previously tested temperature [7]. Other parameters, including relative humidity, were not taken into account, although this parameter may affect the sensation of comfort [22]. The CO_2 concentrations were also not taken into account, because the studies were done without human intervention, and it is humans who generate this pollution [6]. The measurements were carried out in two cars with similar equipment. Studies on such a small sample have previously been published [11, 25].

Limitations and future works

The described studies included a small research sample and included a short measurement period. However, the results are valuable and will be used to formulate directions for further research. The tests should cover a larger sample of test vehicles. It would be worth doing research in real use (RDM). The measurements could be supplemented by indoor air quality tests, including the CO_2 concentration in the cabin.

Studies in buildings show that CO_2 concentration is crucial for perception, and it is an important element of road safety. If thermal comfort improvement systems would also improve perception, then increased costs by increasing the amount of fuel consumed should be secondary, just as improving the quality of indoor air in buildings affects, for example, the development and growth of children [29, 31, 52] or better results at work [38]. Increased emissions when using comfort systems are not conclusive and also require further research. Further research should also demarcate the systems for ensuring adequate air temperature and air exchange. In the near future, the authors planning to publish similar research results conducted for fully electric vehicles.

CONCLUSIONS

The performed analysis allowed an assessment of the changes in the exhaust emissions and fuel consumption in two SUVs of the same model. They were fitted with different engines, but their equipment was similar. The tests were carried out according to the NEDC homologation cycle (guidelines specified in the standard). The application of the comfort systems in both cases influenced the exhaust emissions and fuel consumption. In the case of Vehicle 1, the emission of all exhaust components increased upon the activation of the comfort systems and upon the activation of the sport mode with the exception of PN, which decreased. For Vehicle 2, the results were different. The increase occurred only for the fuel consumption and the emission of carbon oxides.

More precisely speaking, the emission of CO_2 (fuel consumption) on the chassis dynamometer increased upon the activation of the comfort systems from 24 to 29%. With one exception, the emission of gaseous exhaust components on the dynamometer increased by 4–136% (carbon monoxide from 41 to 42%, nitrogen oxides for one case increased by 9%, and for the other decreased to 6%). The emission of PM, depending on the work points, increased by 3% to rise by 43% upon the activation of the comfort systems. It needs to be stressed that the fuel consumption increased by almost 34% with the comfort systems active and with the vehicle operating in the sport mode, which is a significant value directly influencing the operational costs of the vehicle. The performed investigations confirmed that the research of this type is needed and, in the future, should be extended to other types of vehicles including hybrid and electric ones, the share of which in the market is continuously growing.

REFERENCES

1. Akamatsu M., Green P., and Bengler K. 2013. Automotive technology and human factors research: past, present, and future, Int. J. Veh. Technol., 1–27, doi: 10.1155/2013/526180.
2. Pielecha I., Szałek A., and Tchorek G. Jun. 2022. Two generations of hydrogen powertrain—an analysis of the operational indicators in real driving conditions (RDC), Energies, 15(13), 4734, doi: 10.3390/en15134734.
3. Halin A., Verly J.G., and Van Droogenbroeck M. Aug. 2021. Survey and synthesis of state of the art in driver monitoring, Sensors, 21(16), 5558, doi: 10.3390/s21165558.
4. Patrone G.L., Paffumi, E., Otura M., Centurelli M., Ferrarese C., Jahn S., Brenner A., Thieringer B., Braun D., Hoffmann T. Feb. 2022. Assessing the energy consumption and driving range of the QUIET project demonstrator vehicle, Energies, 15(4), 1290, doi: 10.3390/en15041290.
5. Alanazi F. May 2023. Electric vehicles: benefits, challenges, and potential solutions for widespread adaptation, Appl. Sci., 13(10), 6016, doi: 10.3390/app13106016.
6. Nguyen T.A. 2021. Improving the comfort of the vehicle based on using the active suspension system controlled by the double-integrated controller, Shock Vib., 1–11, doi: 10.1155/2021/1426003.
7. Pakusch C., Stevens G., Boden A., and Bossauer P. Jul. 2018. Unintended effects of autonomous driving: A study on mobility preferences in the future, Sustainability, 10(7), 2404, doi: 10.3390/su10072404.
8. "Eurostat report." Accessed: Jul. 10, 2023. [Online]. Available: www.ec.europa.eu/eurostat
9. Mansour C., Bou Nader W., Breque F., Haddad

M., and Nemer M. Jul. 2018. Assessing additional fuel consumption from cabin thermal comfort and auxiliary needs on the worldwide harmonized light vehicles test cycle, Transp. Res. Part Transp. Environ., 62, 139–151, doi: 10.1016/j.trd.2018.02.012.
10. Szymlet N., Lijewski P., and Kurc B. Oct. 2020. Road tests of a two-wheeled vehicle with the use of various urban road infrastructure solutions, J. Ecol. Eng., 21(7), 152–159, doi: 10.12911/22998993/125503.
11. Merkisz J., Dobrzynski M., and Kubiak K. 2017. An impact assessment of functional systems in vehicles on CO 2 emissions and fuel consumption, MATEC Web Conf., 118, 00030, doi: 10.1051/matecconf/201711800030.
12. Lejda K., Jaworski A., Mądziel M., Balawender K., Ustrzycki A., and Savostin-Kosiak D. Mar. 2021. Assessment of petrol and natural gas vehicle carbon oxides emissions in the laboratory and on-road tests, Energies, 14(6), 1631, doi: 10.3390/en14061631.
13. Lijewski P., Merkisz J., Fuć P., Ziółkowski A., Rymaniak Ł., and Kusiak W. Feb. 2017. Fuel consumption and exhaust emissions in the process of mechanized timber extraction and transport," Eur. J. For. Res., 136(1), 153–160, doi: 10.1007/s10342-016-1015-2.
14. Andrych-Zalewska M., Chlopek Z., Merkisz J., and Pielecha J. Nov. 2022. Comparison of gasoline engine exhaust emissions of a passenger car through the WLTC and RDE type approval tests, Energies, 15(21), 8157, doi: 10.3390/en15218157.
15. Woodburn J., Bielaczyc P., Pielecha J., Merkisz J., and Szalek A. Apr. 2021. Exhaust emissions from two euro 6d-compliant plug-in hybrid vehicles: Laboratory and on-road testing, presented at the SAE WCX Digital Summit,, 2021-01–0605. doi: 10.4271/2021-01-0605.
16. Danca P., Vartires A., and Dogeanu A. Jan. 2016. An overview of current methods for thermal comfort assessment in vehicle cabin, Energy Procedia, 85, 162–169, doi: 10.1016/j.egypro.2015.12.322.
17. Mądziel M., Jaworski A., Kuszewski H., Woś P., Campisi T., and Lew K. Dec. 2021. The development of CO_2 instantaneous emission model of full hybrid vehicle with the use of machine learning techniques, Energies, 15(1), 142, doi: 10.3390/en15010142.
18. Pielecha I., Cieslik W., and Szwajca F. Jan. 2023. Energy flow and electric drive mode efficiency evaluation of different generations of hybrid vehicles under diversified urban traffic conditions, Energies, 16(2), 794, doi: 10.3390/en16020794.
19. Dimitrova Z. and Maréchal F. Dec. 2015. Energy integration study on a hybrid electric vehicle energy system, using process integration techniques, Appl. Therm. Eng., 91, 834–847, doi: 10.1016/j.applthermaleng.2015.08.094.
20. Bode F., Burnete N.V., Fechete Tutunaru L., and Nastase I. Mar. 2023. Improving electric vehicle range and thermal comfort through an innovative seat heating system, Sustainability, 15(6), 5534, doi: 10.3390/su15065534.
21. Li N., Liu Y., Zhang J., Li C., Ji Y., and Liu W. Mar. 2022. Research on energy consumption evaluation of electric vehicles for thermal comfort, Environ. Sci. Pollut. Res., doi: 10.1007/s11356-022-19790-y.
22. Basińska M., Ratajczak K., Michałkiewicz M., Fuć P., and Siedlecki M. Nov. 2021. The way of usage and location in a big city agglomeration as impact factors of the nurseries indoor air quality, Energies, 14(22), 7534, doi: 10.3390/en14227534.
23. Gladyszewska-Fiedoruk K. Mar. 2011. Concentrations of carbon dioxide in a car, Transp. Res. Part Transp. Environ., 16(2), 166–171, doi: 10.1016/j.trd.2010.07.003.
24. Gładyszewska-Fiedoruk K. Jun. 2011. Concentrations of carbon dioxide in the cabin of a small passenger car, Transp. Res. Part Transp. Environ., 16(4), 327–331, doi: 10.1016/j.trd.2011.01.005.
25. Zali M.K.A.M. and Sulaiman S.A. Sep. 2022. Study on Air-Circulation Practices in Car Cabin, in 2022 7th International Conference on Electric Vehicular Technology (ICEVT), Bali, Indonesia: IEEE, 205–209. doi: 10.1109/ICEVT55516.2022.9924780.
26. Cichowicz R. and Wielgosiński G. Dec. 2015. Effect of meteorological conditions and building location on CO_2 concentration in the university campus, Ecol. Chem. Eng. S, 22(4), 513–525, doi: 10.1515/eces-2015-0030.
27. Cichowicz R. and Wielgosiński G. Jun. 2018. Analysis of variations in air pollution fields in selected cities in Poland and Germany, Ecol. Chem. Eng. S, 25(2), 217–227, doi: 10.1515/eces-2018-0014.
28. Wei D., Nielsen F., Karlsson H., Ekberg L., and Dalenbäck J.-O. Jan. 2023. Vehicle cabin air quality: influence of air recirculation on energy use, particles, and CO_2, Environ. Sci. Pollut. Res., 30(15), 43387–43402, doi: 10.1007/s11356-023-25219-x.
29. Wei D., Nielsen F., Ekberg L., Löfvendahl A., Bernander M., and Dalenbäck J.-O. Aug. 2020. PM2.5 and ultrafine particles in passenger car cabins in Sweden and northern China—the influence of filter age and pre-ionization, Environ. Sci. Pollut. Res., 27(24), 30815–30830, doi: 10.1007/s11356-020-09214-0.
30. Wei D., Nielsen F., Ekberg L., and Dalenbäck J.-O. Jun. 2022. Size-resolved simulation of particulate matters and CO_2 concentration in passenger vehicle cabins, Environ. Sci. Pollut. Res., 29(30), 45364–45379, doi: 10.1007/s11356-022-19078-1.
31. Weng C.-L. and Kau L.-J. Aug. 2019. Design and implementation of a low-energy-consumption air-conditioning control system for smart vehicle, J. Healthc. Eng., 2019, 1–14, doi: 10.1155/2019/3858560.

32. Tolis E.I., Karanotas T., Svolakis G., Panaras G., and Bartzis J.G. Oct. 2021. Air quality in cabin environment of different passenger cars: effect of car usage, fuel type and ventilation/infiltration conditions, Environ. Sci. Pollut. Res., 28(37), 51232–51241, doi: 10.1007/s11356-021-14349-9.
33. Munahar S., Purnomo B.C., Izzudin M., Setiyo M., and Saudi M.M. Jan. 2022. Vehicle air conditioner (VAC) control system based on passenger comfort: a proof of concept, IIUM Eng. J., 23(1), 370–383, doi: 10.31436/iiumej.v23i1.1812.
34. Alkaabi K. and Raza M. Dec. 2022. Revisiting the dynamics of car cabin environment and driver comfort," Front. Built Environ., 8, 1041305, doi: 10.3389/fbuil.2022.1041305.
35. Krawczyk N., Dębska L., and Białek A. Dec. 2021. Thermal comfort in the modern car-experimental analysis and verification of the fanger model, Int. Rev. Mech. Eng. IREME, 15(12), 609, doi: 10.15866/ireme.v15i12.21473.
36. Dębska L. and Krawczyk N. Jun. 2023. Thermal comfort assessment in the modern passenger car under actual operational conditions, Prod. Eng. Arch., 29(2), 140–146, doi: 10.30657/pea.2023.29.16.
37. Gładyszewska-Fiedoruk K. and Teleszewski T.J. Jun. 2020. Modeling of humidity in passenger cars equipped with mechanical ventilation, Energies, 13(11), 2987, doi: 10.3390/en13112987.
38. Gładyszewska-Fiedoruk K. and Teleszewski T.J. Feb. 2023. Experimental research on the humidity in a passenger car cabin equipped with an air cooling system – development of a simplified model, Appl. Therm. Eng., 220, 119783, doi: 10.1016/j.applthermaleng.2022.119783.
39. Lee M., Chinnasamy V., Shin Y., and Cho H. May 2023. Numerical study on a vehicle driver's thermal comfort when using water thermal seats during summer and winter, J. Mech. Sci. Technol., 37(5), 2593–2606, doi: 10.1007/s12206-023-0434-5.
40. Barrios C.C., Domínguez-Sáez A., Rubio J.R., and Pujadas M. Sep. 2012. Factors influencing the number distribution and size of the particles emitted from a modern diesel vehicle in real urban traffic," Atmos. Environ., 56, 16–25, doi: 10.1016/j.atmosenv.2012.03.078.
41. Jaworski A., Kuszewski H., Wojewoda P., Balawender K., Woś P., Longwic R., Longwic R. Boichenko S. Jul. 2023. Assessment of the effect of road load on energy consumption and exhaust emissions of a hybrid vehicle in an urban road driving cycle—comparison of road and chassis dynamometer tests, Energies, 16(15), 5723, doi: 10.3390/en16155723.
42. Merkisz, J., Mizera, J., Bajerlein, M., Rymaniak, L., Maj, P. 2014. The influence of laser treatment and the application of reduced pressure force piston rings on the engine exhaust emissions under the conditions of engine lubrication with different engine oils. Applied Mechanics and Materials, 518, 102–107.
43. Kim H.J., Lee S.H., Kwon S.II, Park S., Lee J., Keel J.H., Lee J.T., Park S. Sep. 2020. Investigation of the emission characteristics of light-duty diesel vehicles in Korea Based on EURO-VI standards according to type of after-treatment system, Energies, 13(18), 4936, doi: 10.3390/en13184936.
44. Pielecha I. and Szwajca F. Apr. 2023. Combustion of lean methane/propane mixtures with an active prechamber engine in terms of various fuel distribution, Energies, 16(8), 3608, doi: 10.3390/en16083608.
45. Andrych-Zalewska M., Chlopek Z., Merkisz J., and Pielecha J. Feb. 2023. Impact of the internal combustion engine thermal state during start-up on the exhaust emissions in the homologation test, Energies, 16(4), 1937, doi: 10.3390/en16041937.
46. Bodisco T. and Zare A. Jun. 2019. Practicalities and driving dynamics of a real driving emissions (RDE) Euro 6 regulation homologation test, Energies, 12(12), 2306, doi: 10.3390/en12122306.
47. Kurzawska P. and Jasiński R. Mar. 2021. Overview of sustainable aviation fuels with emission characteristic and particles emission of the turbine engine fueled ATJ blends with different percentages of ATJ fuel, Energies, 14(7), 1858, doi: 10.3390/en14071858.
48. Cichowicz R. and Dobrzański M. Nov. 2022. 3D spatial dispersion of particulate matter and gaseous pollutants on a university campus in the center of an urban agglomeration, Energy, 259, 125009, doi: 10.1016/j.energy.2022.125009.
49. Cichowicz R. and Dobrzański M. Jan. 2021. Indoor and outdoor concentrations of particulate matter (PM10, PM2.5) and gaseous pollutants (VOC, H2S) on different floors of a university building: A case study, J. Ecol. Eng., 22(1), 162–173, doi: 10.12911/22998993/128859.
50. Pałaszyńska K., Bandurski K., and Porowski M. 2017. Energy demand and thermal comfort of HVAC systems with thermally activated building systems as a function of user profile, E3S Web Conf., 22, 00130, doi: 10.1051/e3sconf/20172200130.
51. Ratajczak K., Bandurski K., and Płóciennik A. Dec. 2022. Incorporating an atrium as a HAVC element for energy consumption reduction and thermal comfort improvement in a Polish climate, Energy Build., 277, 112592, doi: 10.1016/j.enbuild.2022.112592.
52. Oh J., Wong W., Castro-Lacouture D., Lee J., and Koo C. Jun. 2023. Indoor environmental quality improvement in green building: Occupant perception and behavioral impact, J. Build. Eng., 69, 106314, doi: 10.1016/j.jobe.2023.106314.
53. Wang C., Lin Y., Ptukhin Y., and Liu S. 2023. Air quality in the car: How CO_2 and body odor affect drivers' cognition and driving performance?, SSRN, preprint, doi: 10.2139/ssrn.4525547.

54. Ratajczak K. 2022. Ventilation strategy for proper IAQ in existing nurseries buildings - Lesson learned from the research during COVID-19 pandemic, Aerosol Air Qual. Res., 22(3), 210337, doi: 10.4209/aaqr.210337.
55. Cichowicz R., Sabiniak H., and Wielgosińsk G. Mar. 2015. The influence of a ventilation on the level of carbon dioxide in a classroom at a higher university / wpływ Wentylacji na poziom ditlenku węgla w pomieszczeniu uczelni wyższej, Ecol. Chem. Eng. S, 22(1), 61–71, doi: 10.1515/eces-2015-0003.
56. Ratajczak K. and Basińska M. Apr. 2021. The well-being of children in nurseries does not have to be expensive: the real costs of maintaining low carbon dioxide concentrations in nurseries, Energies, 14(8), 2035, doi: 10.3390/en14082035.
57. Laska M. and Dudkiewicz E. 2017. Research of CO_2 concentration in naturally ventilated lecture room," E3S Web Conf., 22, 00099, doi: 10.1051/e3sconf/20172200099.
58. Marczak H, Droździel P. 2021. Analysis of pollutants emission into the air at the stage of an electric vehicle operation. Journal of Ecological Engineering. 22(8), 182–188. doi: 10.12911/22998993/140256.
59. Rayapureddy S.M., Matijošius J., Rimkus A., Caban J., Słowik T. 2022. Comparative study of combustion, performance and emission characteristics of hydrotreated vegetable oil–biobutanol fuel blends and diesel fuel on a CI engine. Sustainability. 14(12), 7324. doi: 10.3390/su14127324.
60. Kuranc A., Caban J., Šarkan B., Dudziak A., Stoma M. 2021. Emission of selected exhaust gas components and fuel consumption in different driving cycles. Communications - Scientific letters of the University of Zilina. 23. B265-B277. 10.26552/com.C.2021.4.B265-B277.
61. Yang L., Ji S., Niu W., Zare A., Hunicz J., Brown R.J. 2024. Effect of split injection strategy of diesel fuel on multi-stage heat release and performance of a RCCI engine fueled with diesel and natural gas, Fuel, 362, 130930, doi: 10.1016/j.fuel.2024.130930.
62. Hudec J., Šarkan B., Czödörová R., Caban J. 2021. The influence of quality management system on the operation of periodical technical inspection stations. Applied Sciences. 11(11), 4854. doi: 10.3390/app11114854.
63. Žvirblis T., Hunicz J., Matijošius J., Rimkus A., Kilikevičius A., Gęca M. 2023. Improving diesel engine reliability using an optimal prognostic model to predict diesel engine emissions and performance using pure diesel and hydrogenated vegetable oil. Eksploatacja i Niezawodność – Maintenance and Reliability. 25(4). doi:10.17531/ein/174358.
64. Caban J., Kuranc A., Sarkan B., Sejkorova M., Loman M. 2022. Porównanie emisji spalin z silników pojazdów ciężarowych zasilanych olejem napędowym (ON) oraz gazem ziemnym (LNG) w warunkach rzeczywistej eksploatacji. Przemysł Chemiczny, 1, 37–41. doi: 10.15199/62.2022.1.2