Impact of using Tobacco Heating System (THS) on indoor air quality in a night club

Violeta Kaunelienė[1*], Marija Meišutovič-Akhtarieva[1], Tadas Prasauskas[1], Darius Čiužas[1], Edvinas Krugly[1], Karolina Keraitytė[1], Dainius Martuzevičius[1]

[1] Department of Environmental Technology, Faculty of Chemical Technology, Kaunas University of Technology, Radvilenu pl. 19, Kaunas LT50254, Lithuania

Abstract

Heating tobacco instead of burning offers a potentially lower risk of delivering nicotine compared to conventional cigarettes. The majority of heat-not-burnt tobacco product studies have been related to the mainstream aerosol, but the data on the second hand aerosol is yet limited to several chamber studies, impact on indoor air quality in real life settings has not been yet reported. Here we assess pollution generated by tobacco heating system in a hospitality venue. Volunteers used tobacco heating system in a night club during non-operation hours. Additionally, indoor air quality was assessed while club in operation. Real-time aerosol particle concentration and off-line carbonyl, nicotine and 3-ethenylpyridine concentration was measured. Observed levels of particle number concentration was as follows: background at 1E+4 # cm^{-3}, 10 users at 5E+4 # cm^{-3}, 30 users at 1E+5 # cm^{-3} and club in operation at 1E+6 # cm^{-3} – 1E+7 # cm^{-3}. This represents an increase by an order of magnitude in each subsequent scenario. The club featured relatively high background concentrations of gaseous pollutants presumably due to the third hand smoke. The impact of the usage of THS in non-operating club to the gaseous pollutant variation was much lower if at all significant compared to particle concentrations. The usage of tobacco heating system resulted in increasing particle number and mass concentrations from the background by an order of magnitude, but yet were an order of magnitude lower compared to club in operation. The majority of gaseous pollutant concentration were not affected, except nicotine.

Keywords: indoor air quality, heat not burnt, environmental tobacco aerosol, nicotine, hospitality venue.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

INTRODUCTION

Tobacco use is the leading cause of global preventable morbidity and mortality. In spite of much evidence on the adverse health effects of tobacco use, many people continue to smoke (Xiangyu et al., 2018). Tobacco cigarette use is a highly addictive habit, making cessation a difficult and challenging task (Farsalinos et al., 2017). There is an increasing focus on developing harm reduction strategies to address the health risks of conventional cigarettes (CCs) (Lüdicke et al., 2018). Electronic cigarettes (ECs) are currently the most popular harm-reduction products, but many smokers do not find them sufficiently effective or satisfactory in fully substituting smoking (Farsalinos et al., 2017). Heating tobacco instead of burning can offer a potentially lower risk of delivering nicotine compared to CCs because it creates a less complex aerosol than burned tobacco (Jaccard et al., 2017). Moreover, research on heat-not-burnt (HnB) tobacco products (or alternatively called Tobacco Heating System (THS), Novel Tobacco Product (NTB)) has consistently demonstrated that harmful and potentially harmful constituents (HPHCs) are reduced or absent in the aerosols of heated tobacco. Simonavicius et al. reviewed 31 publication on HnB products and concluded that compared with CCs, HnB products delivered up to 83% of nicotine and reduced levels of harmful and potentially harmful toxicants by at least 62% and particulate matter (PM) by at least 75% (Simonavicius et al., 2018). Most of studies however were related to the mainstream aerosol. The data on the second hand HnB aerosol is yet limited to several studies (Mottier et al. (2016); Mitova et al. (2016); Protano et al. (2016); Ruprecht et al. (2017); Ichitsubo et al. (2018); Meišutovič-Akhtarieva et al. (2019)).

The concentrations of most investigated indoor air constituents during the use of HnB products in an environmentally controlled environments are similar to background levels (with the exception of aldehydes) and an order of magnitude lower than in the CC environmental aerosol (Mitova et al., (2016); Ichitsubo et al. (2018); Ruprecht et al. (2017); Meišutovič-Akhtarieva et al. (2019)).

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

The review by Kaunelienė et al. (2018) provided a comparative analysis of THS generated pollution against general indoor air quality (IAQ) in various micro-environments, especially with combustion-based pollution sources present. The use of THS (as well as EC) in the controlled environment was found to result in the lowest concentrations of formaldehyde, benzene, toluene, and $PM_{2.5}$ (particles with aerodynamic diameter lower than 2.5 μm) among majority researched pollution sources (CC, water-pipe, incense, mosquito coils). The exposure to significantly higher pollution levels of benzene, toluene and formaldehyde may occur in public environments, especially transport micro-environments.

Following the adoption of WHO Framework Tobacco Control Convention in 2003, smoking bans in public places have been introduced in many countries (WHO, 2017). A wide range of regulatory responses ranging from no regulation to complete bans were also applied to the harm-reduction products (Etter et al., 2011). Bans against the use of nicotine containing products in public spaces at many countries is possibly the main reason that the evidence on the passive exposure to the vapour released or exhaled from the harm-reduction products under real conditions is still scarce. Only four studies on the impact of EC to IAQ performed using human volunteers in natural settings were reported in a systematic review by Abidin et al. (2017).

The impact of HnB products on IAQ in real life settings has not been investigated so far. The aim of this study was to simulate the variation of IAQ following the usage of HnB product (namely, THS) in a non-operating night club with varying amount of users, and compare it against the typical IAQ in a night club under operation.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

METHODS

Test product

Tobacco heating system THS 2.2 (further referred to as IQOS) with HEETS Bronze Label fillings (Philip Morris International Inc., USA) were used.

Premises

The experiment was conducted in a night club in Kaunas, Lithuania, with the floor area of approx. 160 m^2 and the volume of approx. 880 m^3. The club premises may be subjectively divided to several areas, including wardrobe, bar area, DJ scene, the main dancing floor, and seating areas (Fig. S1). The facility was equipped with a mechanical ventilation system, supplying the air via air handling unit equipped with rotary heat exchanger, 9100 m^3 h^{-1} maximum air flow. However, this air handling unit was operated manually, while most of the time the club has been operated in the natural ventilation regime (0.5 ACH as determined by the CO_2 concentration decay after the closure). The indoor of club was a non-smoking area following a smoking ban in public premises in Lithuania. The smoking room was located outdoors with the entrance from the main club area. During operation the club was attended by 200 – 400 people at the time, while the smoking room may accommodate approx. 30 humans. No cooking activities took place in a club, only drinks and occasionally cold appetizers were served.

Experimental procedure

The experiment was performed in February 2018 during the course of two campaigns. The first campaign was carried out in non-working hours of the club to evaluate THS generated pollution while avoiding presence of other active pollution sources. Three days of experiment, each

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

consisting of five measurement sessions (Campaign #1): background; background with 10 humans present but without THS use; 10 humans simultaneously using THS; background with 30 humans present but without THS use; 30 humans THS used by scattered all over the main club area. Each measurement session took 30 minutes. The experiments were conducted with only natural ventilation present (air handling unit off), since this reflects usual condition of a nightclub. After the measurement session, particle and CO_2 concentration were reduced to the background levels after both IQOS usage sessions via purging indoor air by running air handling unit at 75% capacity (equivalent to 7-8 ACH) for 30 min. Indoor air was sampled at the breathing height (1.5 m from the floor) at two locations, representing different type of occupancy: the main (dance floor) area of the club (further referred to as Zone 1) and sitting area (Zone 2) (see Fig.S1). Zone 2 was located under a balcony thus restricted airflows around it, presumably decreasing the dispersion rate of the exhaled aerosol.

The second campaign was carried out for three days (Campaign #2). During each day, one hour before the club opening (representing background) and 3 hours of club in operation were sampled in order to obtain the profile of IAQ occurring during typical club activities. During the third day, the real-time measurements were extended for 4 additional hours to obtain variation of pollutant concentrations until and after the closure of the club. Similar sampling locations were employed as in Campaign #1. The ventilation during Campaign #2 was adjusted manually running air handling unit at 25% (equiv. of 2.6 ACH) capacity with no attendees to 100% (equiv. of 10 ACH) capacity with the maximum attendees (~400 people).

Analytics

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

The real-time particle number concentration (PNC), CO_2 concentration, relative humidity, and temperature, as well as off-line carbonyls (acetaldehyde and formaldehyde), off-line nicotine and 3-ethenylpyridine concentration were analysed.

The real-time size-segregated particle concentration have been measured using the electrical low pressure impactor (ELPI+, Dekati, Inc., Finland), at a flow rate of 10 l min^{-1}. Real-time concentrations of aerosol samples have been registered in 1 Hz or 10 Hz intervals. The sampling airflow was being switched between Zone 1 and Zone 2 using a 3-way switching valve every 5 minutes. The sample was delivered to particle sampler using Tygon® formula E-3603 laboratory tubing. Such tubing has been confirmed as the best compromise considering particle losses (Asbach et al., 2016).

The values of carbon dioxide (CO_2), temperature, and relative humidity have been continuously recorded by air quality meters (7545 IAQ-CALC, TSI Inc., USA).

Concentration of nicotine and 3-ethenylpyridine (3-EP) has been estimated following the ISO 18145 procedure which is based on the collection of compounds by adsorption on a sorbent resin (XAD®-4.7 x 70-mm size, 2 sections, 40/80 mg sorbent, 20/40 mesh, SKC Inc.), extraction and determination by gas chromatography-mass spectrometry (GC-MS-QP2010 Ultra, Shimadzu Corp., Japan). Concentration of formaldehyde and acetaldehyde has been estimated following the ASTM D5197-03 procedure based on sample collection on a silica gel coated with 2,4-dinitrophenylhydrazine (DNPH) reagent (SKC Inc.). The DNPH derivatives were analysed for parent aldehydes utilizing high performance liquid chromatography (HPLC-DAD (UV)).

Data processing and analysis

The measured distributions were based on PNC (unit particles/cm^3 or # cm^{-3}). The particle size distribution (PSD) was based on the number density (concentration) distribution function, which

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

represented particle concentration normalized to the particle size bin where it was measured, i.e., the number of particles per volume of air with sized between Dp and dDp. This is usually expressed mathematically as Dp = dN/dlogDp (# cm^{-3}). The PSD data was adjusted for particle losses in the sampling lines due to diffusion and inertial/gravitational losses for each channel separately.

RESULTS AND DISCUSSION

Time resolved variation of aerosol concentrations

Highly time resolved aerosol concentration has been measured across the entire experiment, including both controlled usage of IQOS (Campaign #1), as well as the uncontrolled operation of the club (Campaign #2). The time series of PNC during the two measurement campaigns are shown in Fig. 1.

The controlled experiment (Campaign #1) started with the background, having the median concentration of particles 9.4E+3 # cm^{-3} and 9.8E+3 # cm^{-3} in Zones 1 and 2, respectively. This is a moderate concentration of particles observable in many general indoor living environments, usually ranging within 1E+3 to 9E+4 # cm^{-3} (Fromme, 2012). This background was measured in the premises where no continuous activities were present after a several days of workweek closure before the opening in the weekend. The entry of 10 volunteers did not affect the background concentration, with the median concentrations remaining at 9.2E+3 # cm^{-3} and 9.9E+3 # cm^{-3} in Zones 1 and 2, respectively. Moreover, no major variation of particle concentration has been registered. Human movement may have resulted into resuspension of dust, but such super-micrometer particles were not reflected well in total particle concentration variation, possibly due to losses in the sampling line transport.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

Once the ten volunteers started using IQOS devices, the concentration of particles has increased, as reflected by the first peak (Fig.1(A). The maximum has been registered at 1.2E+5 # cm^{-3}, while the median concentrations were at 3.6E+4 # cm^{-3} and 3.5E+4 # cm^{-3} in Zones 1 and 2, respectively. This is a statistically significant increase ($p<0.05$). Such level of particles is comparable to our simulation measurements in a room-scaled chamber with one volunteer and ventilation rate 0.5 (Meišutovič-Akhtarieva et al., 2019). At the same time, this is relatively low level compared to other hospitality environments even with smoking absent. In Germany very high median PNCs of 2.2E+5 # cm^{-3} were measured during four main visiting hours in non smoking areas in four cafés/restaurants, 1.1E+5 # cm^{-3} in two bars and 2.9E+5 # cm^{-3} in seven discos (Bolte et al., 2008).

Once usage of 10 IQOS stopped, the concentration started decaying due to natural ventilation and further due to purging with forced ventilation to level of 4E+4 # cm^{-3} (CO_2 level between 460-480 ppm), which served as a background concertation for 30 volunteers present in the premises.

Thirty IQOS users resulted in another significant increase of PNC to maximum value of 1.5E+5 # cm^{-3}, and median of 1.2E+5 # cm^{-3} in Zone 1 and 1.3E+5 # cm^{-3} in Zone 2. Such levels are comparable of the one registered in room chamber with 5 volunteers using IQOS (Meišutovič-Akhtarieva et al., 2019) and in the higher range of hospitality environments such as German restaurants, pubs and discotheques, ranging from 1.2E+5 # cm^{-3} to 2.1E+5 # cm^{-3} (Bolte et al., 2008). The concentration has not decreased quickly to the background. This did not agree with our findings from the simulations in a room chamber, where we observed a rapid decay of concentrations to background levels, and attributed it to the short life span of volatile particles. Such difference from chamber findings is probably due to a much more intensive emission having 30 simultaneous users, as well as lower ventilation, having air handling unit off (air exchange rate approx. 0.5 ACH) during the test.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

The preparations for the club opening (Campaign #2) already resulted in high background values (of 2.7E+5 # cm^{-3} in Zone 1 and 2.9E+5 # cm^{-3} in Zone 2, Fig. 1(B)). Yet the club operation resulted in the highest PNC (max 1.7E+7 # cm^{-3}, median 7.3E+5 # cm^{-3} in Zone 1 and 8.0E+5 # cm^{-3} in Zone 2), which is statistically significantly higher compared to both background of the same day, but more importantly, all the scenarios involving IQOS usage. Such levels and variation is a result of the local particle sources, among most important were the operation of artificial fog machine as well as fugitive emissions from the adjacent smoking room, as confirmed further by the concentrations of CC markers. The particle levels were generally high, comparable to those registered in a chamber during the use of CC (Meišutovič-Akhtarieva et al., 2019), and higher in German hospitality environments involving smoking of tobacco (Bolte et al., 2008).

A general trend comparing results of PNC increase from both measurement campaigns was as follows: background at 1E+4 # cm^{-3}, 10 IQOS at 5E+4 # cm^{-3}, 30 IQOS at 1E+5 # cm^{-3} and club in operation at 1E+6 # cm^{-3} – 1E+7 # cm^{-3}. This represents an increase by an order of magnitude in each subsequent scenario.

Particle mass concentrations

The particle mass concentration (PMC) as calculated from real-time ELPI+ measurements was grouped based on the measurement scenarios (Fig. 2). Generally, $PM_{2.5}$ and PM_{10} displayed similar variations between the measurement scenarios, except that PM_{10} indicated longer tails of distribution (represented by both 5th and 95th percentile whiskers), suggesting that there was higher variation of concentration. This is due to the fact that PM_{10} is more influenced by resuspended dust, associated with human activities, while $PM_{2.5}$ is associated with primary and

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

secondary particles, resulting from thermal aerosol release (such as fog machines, cigarette smoking, or exhalation of cigarette aerosol).

The scenarios from background to using of 30 IQOS devices did not result in significant increase in PMC, with the median $PM_{2.5}$ ranging from 2.7 μg m^{-3} at Zone 1 and 2.8 μg m^{-3} at Zone 2 in case of background to 11.4 μg m^{-3} (Zone 1) and 12.3 μg m^{-3} (Zone 2) in case of 30 IQOS. Such comparatively low impact of IQOS usage to indoor PMC may have been resulted due to the fact that the majority of particles was located in sub-micrometer size range (as discussed in the following subchapter) thus not carrying much mass. Another issue may be associated with the particle mass loss during the transport in sampling lines, since particles may have partially evaporated.

The operating club resulted in significantly higher concentrations compared to 30 IQOS users. Preparations to the club opening already resulted higher $PM_{2.5}$ concentrations, this time having spatial variations between Zone 1 (59.0 μg m^{-3}) and Zone 2 (35.0 μg m^{-3}). This may be associated with more intensive staff moving and re-suspending particles from surfaces, as well as potential secondary tobacco aerosol brought by staff from smoking room.

Further on, club in operation resulted almost several orders of magnitude higher median $PM_{2.5}$ (3715 μg m^{-3} at Zone 1 and 1770 μg m^{-3} at Zone 2) and PM_{10} (4590 μg m^{-3} at Zone 1 and 2470 μg m^{-3} at Zone 2) concentrations.

These levels are significantly higher than $PM_{2.5}$ concentration in hospitality venues (36-869 μg m^{3}) as reviewed by Fromme et al. (2012) in smoking areas of Californian casinos during the periods of the highest occupancy (median 44-110 μg m^{-3}) (Klepeis et al., 2012) or German discotheques (median 599.2 μg m^{-3}) during the principal business hours before implementation of partial smoking ban (Gleich et al., 2011) and are closer to the mean $PM_{2.5}$ and PM_{10} concentrations (619.1 μg m^{-3} and 1156.6 μg m^{-3}) during rush working hours (17–21) at the

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

combined water-pipe/CC smoking cafes in Tehran (Heydari et al., 2019). It must be noted that such differences in case of our measurements possibly result from the deriving of mass concentration from the real-time PNC measurements, as opposed to the filter based collection. In the latter method, filters are conditioned before the gravimetric analysis, thus loosing significant portion of the mass in case of volatile aerosol, which seems to be the case in our measurements, as indicated by the PSD analysis in the following subchapter.

Particle size distributions

The PSDs based on PNC indicated that the major part of particles were of sub-micrometer size range, and more importantly, sub 100 nm range (Fig. 3(A)). It may be expected that aerosol in premises with thermal sources would have a mode at 80-100 nm range, indicating accumulating particles (Bolte et al., 2008). However, the ultrafine mode indicates that major portion of particles were at nucleation size range for all measurement scenarios. We have observed such phenomena in chamber for the exhaled THS aerosol and attributed such distribution to the rapidly evaporating volatile matter of the exhaled aerosol, which may reach 95% of total mass. Moreover, the measured RH levels during IQOS experiment averaged at 36-43%, which has been indicated as favourable range for the particle evaporation (Meišutovič-Akhtarieva et al., 2019). Club in operation yielded similar PSD, possibly reflecting the presence of highly volatile aerosol from fog machine, while RH stayed relatively low (29-35%).

The PSD based on the mass concentration (Fig. 3(B)) indicated the mode at 200-300 nm during the use of IQOS and at ~1 μm during club in operation. The latter is associated with the fact that particle number concentration was significantly higher in that range, compared to IQOS. The PSD in the range of 2-10 μm had much uncertainty associated with particle losses during sampling thus could not be estimated quantitatively with high accuracy, but expectedly it should

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

feature a mode in particle mass caused by the re-suspended dust from the moving personnel and visitors.

Gaseous pollutants

The club featured relatively high background concentrations of gaseous pollutants (Fig. 4 and Table S1). The mean background concentration of formaldehyde (37.4 μg m^{-3}) and acetaldehyde (41.1 μg m^{-3}) were higher than typically found in residential and public environments (Kaunelienė et al., 2018). The mean background concentration of nicotine (3.4 μg m^{-3}) and 3-EP (1.7 μg m^{-3}) were similar to those measured in non-smoking areas of Finnish nightclubs and discos during peak hours (geometric mean of 2.9 μg m^{-3} and 0.8 μg m^{-3}, respectively) (Johnsson et al., 2006). Presumably, fugitive emissions from the smoking room as well as exhaled cigarette smoke, emissions from clothing and hair from returning smokers to the main club area resulted in substantial adsorption of tobacco combustion products and subsequent re-emission, so called third hand smoke.

The impact of the usage of THS in non-operating club to the gaseous pollutant variation was much lower if at all significant compared to particle concentrations (Fig. 4). The usage of 30 IQOS caused slight increase of concentrations as compared to 10 IQOS, however increased significantly only for formaldehyde and acetaldehyde in Zone 1 ($p<0.05$). Hypothetically, the usage of IQOS in Zone 2 should have been resulted in higher concentrations in comparison to Zone 1 due to restricted dispersion. This hypothesis has been partially confirmed for formaldehyde, acetaldehyde and nicotine (10 IQOS), but the differences did not appear to be statistically significant.

The club in operation resulted in either the similar levels of pollutants to 30 IQOS (formaldehyde, nicotine in Zone 2) or higher pollutant levels (3-EP, statistically significantly acetaldehyde).

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

Although the club is a non-smoking environment, Zone 2 was most likely affected by fugitive emissions of tobacco smoke from the adjacent smoking room. This is evidenced by increased concentrations of tobacco-specific markers – nicotine and 3-EP. Elevated levels of acetaldehyde may be attributed to the consumption of alcohol-containing beverages, as acetaldehyde is a product of ethanol metabolism and is present in the exhaled breath (Bagnardi et al., 2001).

The observed levels of nicotine during the use of 30 IQOS and club in operation were at same range compared to the concentrations in the smoking areas of Finnish nightclubs and discos during peak hours (geometric mean 11.0 μg m^{-3} and 2.4 μg m^{-3}, respectively, Johnsson et al. (2006), Las Vegas casinos where smoking is still not banned (6.7 μg m^{-3}, Achutan et al. (2011)), New York City hookah bars during hours of the highest occupancy (4.2 μg m^{-3}, Zhou et al. (2015)).

Penetration of pollutants from smoking areas to non-smoking areas has been reported in multiple earlier research campaigns. South Australian pubs, clubs, and cafes having separately enclosed smoking areas had lower mean levels of nicotine 4.4 μg m^{-3} compared to the unenclosed ones (7.5 μg m^{-3}), while air of smoking areas contained nicotine concentration of 15 μg m^{-3} measured over a period of 2 – 4 h during a normal to busy dinner or lunch sessions (Cenko et al., 2004). Pollutant concentrations were significantly higher in Spanish hospitality venues with outdoor smokers close to the entrance than in those without outdoor smokers measured during the same range of hours (morning/afternoon) (López et al., 2013).

CONCLUSIONS

The usage of THS in the night club hospitality environment resulted in increasing particle number and mass concentrations from the background by the order of magnitude, but were an order of magnitude lower compared to club in operation, having fugitive emissions from adjacent

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

smoking room and fogging machines. Particles generated by THS usage as well as generated in operating club demonstrated high volatility as indicated by significant nucleation mode in particle distribution. At the same time, the use of IQOS did not significantly affect the concentration of the majority of gaseous pollutants in the club having high background concentration values of tobacco smoke related pollutants.

While the potential observed impact of intensive IQOS usage (such as 30 simultaneous users) in indoor hospitality environments may be associated with the deteriorating indoor air quality and increase exposure to nicotine and acetaldehyde, as well as particles, care should be taken that despite the partial ban smoking of traditional cigarettes may still be the most important factor affecting the exposure of visitors in the night club hospitality environment.

ACKNOWLEDGMENTS

Staff of the night club Mojo Lounge in Kaunas is acknowledged for the possibility to perform the experiment. Ms Lauryna Dabasinskaite is acknowledged for the technical assistance during experiments.

DISCLAIMER

This research was funded by an Investigator-Initiated Study award by Philip Morris Products SA (IIS.PMI.2017.16). The study protocol was written by the investigator, who also conducted the study. Philip Morris Products SA had no involvement in the study conduct, data analysis, and writing of the manuscript.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

REFERENCES

Asbach, C., Kaminski, H., Lamboy, Y., Schneiderwind, U., Fierz, M., & Todea, A. M. (2016). Aerosol Science and Technology Silicone sampling tubes can cause drastic artifacts in measurements with aerosol instrumentation based on unipolar diffusion charging Silicone sampling tubes can cause drastic artifacts in measurements with aerosol instrumentation based on unipolar diffusion charging. *Aerosol Science and Technology*, *50*, 1375–1384. https://doi.org/10.1080/02786826.2016.1241858

Bagnardi, V., Blangiardo, M., La Vecchia, C., & Corrao, G. (2001). Alcohol consumption and the risk of cancer: a meta-analysis. *Alcohol Research & Health : The Journal of the National Institute on Alcohol Abuse and Alcoholism*, *25*(4), 263–270. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/11910703

Bolte, G., Heitmann, D., Kiranoglu, M., Schierl, R., Diemer, J., Koerner, W., & Fromme, H. (2008). Exposure to environmental tobacco smoke in German restaurants, pubs and discotheques. *Journal of Exposure Science and Environmental Epidemiology*, *18*(3), 262–271. https://doi.org/10.1038/sj.jes.7500590

Cenko, C., Pisaniello, D., & Esterman, A. (2004). A study of environmental tobacco smoke in South Australian pubs, clubs and cafes. *International Journal of Environmental Health Research*, *14*(1), 3–11. https://doi.org/10.1080/09603120310001633903

Etter, J. F., Bullen, C., Flouris, A. D., Laugesen, M., & Eissenberg, T. (2011). Electronic nicotine delivery systems: A research agenda. *Tobacco Control*, *20*(3), 243–248. https://doi.org/10.1136/tc.2010.042168

Farsalinos, K. E., Yannovits, N., Sarri, T., Voudris, V., & Poulas, K. (2017). Nicotine Delivery to the Aerosol of a Heat-Not-Burn Tobacco Product: Comparison With a Tobacco Cigarette and E-Cigarettes. *Nicotine & Tobacco Research*, *00*(00), 1–6. https://doi.org/10.1093/ntr/ntx138

Fromme, H. (2012). Particles in the Indoor Environment. In *Air Quality – Monitoring and Modeling* (pp. 117–144). https://doi.org/10.5772/34319

Gleich, F., Mons, U., & Pötschke-Langer, M. (2011). Air contamination due to smoking in German restaurants, bars, and other venues--before and after the implementation of a partial smoking ban. *Nicotine & Tobacco Research : Official Journal of the Society for Research on Nicotine and Tobacco*, *13*(11), 1155–1160. https://doi.org/10.1093/ntr/ntr099

Heydari, G., Taghizdeh, F., Fazlzadeh, M., Jonidi Jafari, A., Asadgol, Z., Mehrizi, E. A., … Arfaeinia, H. (n.d.). Levels and health risk assessments of particulate matters (PM 2.5 and PM 10) in indoor/outdoor air of waterpipe cafés in Tehran, Iran. https://doi.org/10.1007/s11356-019-04202-5

Ichitsubo, H., & Kotaki, M. (2018). Indoor air quality (IAQ) evaluation of a Novel Tobacco Vapor (NTV) product. *Regulatory Toxicology and Pharmacology*, *92*(December 2017), 278–294. https://doi.org/10.1016/j.yrtph.2017.12.017

Jaccard, G., Tafin Djoko, D., Moennikes, O., Jeannet, C., Kondylis, A., & Belushkin, M. (2017). Comparative assessment of HPHC yields in the Tobacco Heating System THS2.2 and commercial cigarettes. *Regulatory Toxicology and Pharmacology*, *90*, 1–8. https://doi.org/10.1016/j.yrtph.2017.08.006

Johnsson, T., Tuomi, T., Riuttala, H., Hyvärinen, M., Rothberg, M., & Reijula, K. (2006). Environmental tobacco smoke in finnish restaurants and bars before and after smoking restrictions were introduced. *Annals of Occupational Hygiene*, *50*(4), 331–341. https://doi.org/10.1093/annhyg/mel011

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

Kaunelienė, V., Meišutovič-Akhtarieva, M., & Martuzevičius, D. (2018, September). A review of the impacts of tobacco heating system on indoor air quality versus conventional pollution sources. *Chemosphere*. https://doi.org/10.1016/j.chemosphere.2018.05.039

Klepeis, N. E., Omoto, J., Ong, S. L., Omoto, H. S., & Dhaliwal, N. (2012). Small proportions of actively-smoking patrons and high PM2.5 levels in southern California tribal casinos: support for smoking bans or designated smoking areas. *BMC Public Health*, *12*, 819. https://doi.org/10.1186/1471-2458-12-819

López, M. J., Fernández, E., Pérez-Rios, M., Martínez-Sánchez, J. M., Schiaffino, A., Galán, I., … Nebot, M. (2013). Impact of the 2011 spanish smoking ban in hospitality venues: Indoor secondhand smoke exposure and influence of outdoor smoking. *Nicotine and Tobacco Research*, *15*(5), 992–996. https://doi.org/10.1093/ntr/nts218

Lüdicke, F., Picavet, P., Baker, G., Haziza, C., Poux, V., Lama, N., & Weitkunat, R. (2018). Effects of switching to the Tobacco Heating System 2.2 menthol, smoking abstinence, or continued cigarette smoking on biomarkers of exposure: A randomized, controlled, open-label, multicenter study in sequential confinement and ambulatory settings (Part 1. *Nicotine and Tobacco Research*, *20*(2), 161–172. https://doi.org/10.1093/ntr/ntw287

Meišutovič-Akhtarieva, M., Prasauskas, T., Čiužas, D., Krugly, E., Keraitytė, K., Martuzevičius, D., & Kaunelienė, V. (2019). Impacts of exhaled aerosol from the usage of the tobacco heating system to indoor air quality: A chamber study. *Chemosphere*, *223*, 474–482. https://doi.org/10.1016/j.chemosphere.2019.02.095

Mitova, M. I., Campelos, P. B., Goujon-Ginglinger, C. G., Maeder, S., Mottier, N., Rouget, E. G. R., … Tricker, A. R. (2016). Comparison of the impact of the Tobacco Heating System 2.2 and a cigarette on indoor air quality. *Regulatory Toxicology and Pharmacology*, *80*, 91–101. https://doi.org/10.1016/j.yrtph.2016.06.005

Mottier, N., Tharin, M., Cluse, C., Crudo, J. R., Lueso, M. G., Goujon-Ginglinger, C. G., … Solioz, J. (2016). Validation of selected analytical methods using accuracy profiles to assess the impact of a Tobacco Heating System on indoor air quality. *Talanta*, *158*, 165–178. https://doi.org/10.1016/j.talanta.2016.05.022

Ruprecht, A. A., De Marco, C., Saffari, A., Pozzi, P., Mazza, R., Veronese, C., … Boffi, R. (2017). Environmental pollution and emission factors of electronic cigarettes, heat-not-burn tobacco products, and conventional cigarettes. *Aerosol Science and Technology*, *51*(6), 674–684. https://doi.org/10.1080/02786826.2017.1300231

Simonavicius, E., Mcneill, A., Shahab, L., & Brose, L. S. (2018). Heat-not-burn tobacco products: a systematic literature review. *Tob Control*, *0*, 1–13. https://doi.org/10.1136/tobaccocontrol-2018-054419

WHO. (2017). *Monitoring tobacco use and prevention policies, World Health Organization*. Retrieved from http://apps.who.int/bookorders.

Xiangyu, Li; Yanbo, Luo; Xingyi, Jiang; Hongfei, Zhang; Fengpeng, Zhu; Shaodong, Hu; Hongwei, Hou; Qingyuan, Hu; Yongqiang, P. (2018). Chemical Analysis and Simulated Pyrolysis of Tobacco Heating System 2.2 Compared to Conventional Cigarettes. *Nicotine & Tobacco Research*.

Zhou, S., Weitzman, M., Vilcassim, R., Wilson, J., Legrand, N., Saunders, E., … Gordon, T. (2015). Air quality in New York city hookah bars. *Tobacco Control*, *24*(E3), e193–e198. https://doi.org/10.1136/tobaccocontrol-2014-051763

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

Figure Captions

Figure 1. Variations of PNC (# cm^{-3}) during controlled use of simultaneous 10 and 30 IQOS devices (above) and during uncontrolled operation of the club (below).

Figure 2. Particle mass ($PM_{2.5}$ and PM_{10}) and number (PN_{10}) concentrations in Zone 1 and Zone 2 under controlled conditions (10 IQOS and 30 IQOS) and club in operation (Club OP). Backgr.+10p. – background with 10 humans present but without THS use; Backgr.+30p. - background with 30 humans present but without THS use.

Figure 3. Particle size distribution of particle number concentration (A) and particle mass concentration (B) during the use of THS under controlled conditions (10 IQOS and 30 IQOS) and club in operation.

Figure 4. Concentration of gaseous pollutants under different scenarios: 10 volunteers using IQOS (10 IQOS), 30 volunteers using IQOS (30 IQOS) and club in operation (CLUB OP); Z1 - Zone 1, Z2 - Zone 2. Background subtracted values are indicated as dots.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

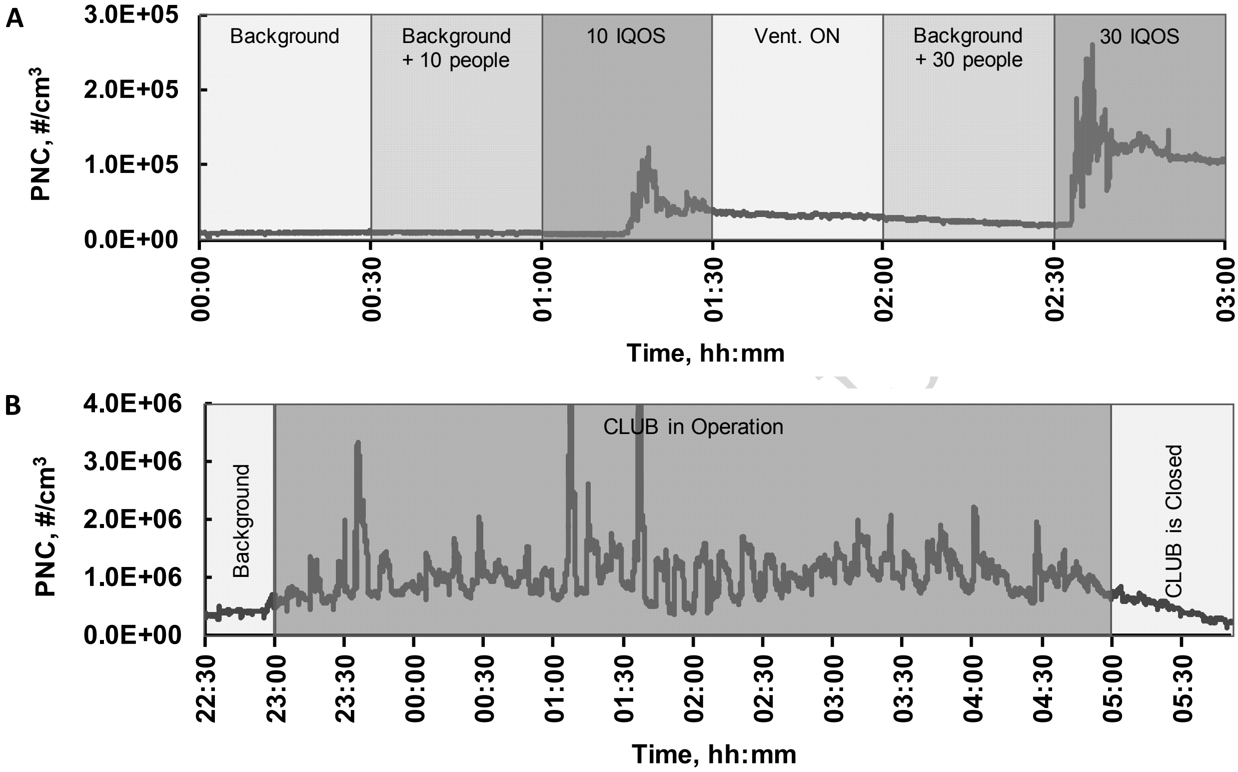


Fig.1.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

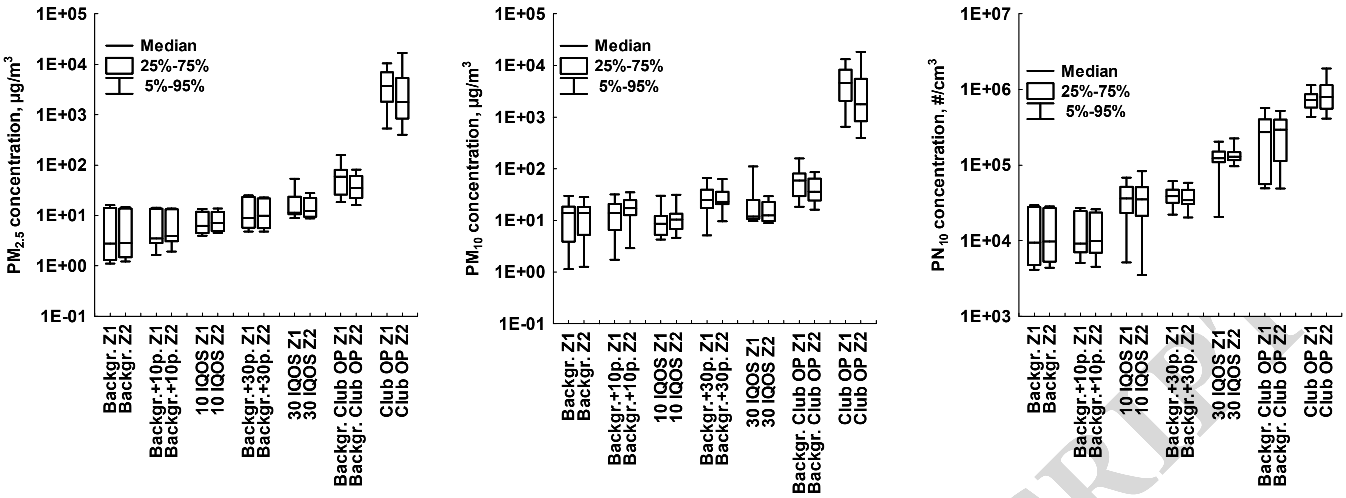


Fig.2.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt

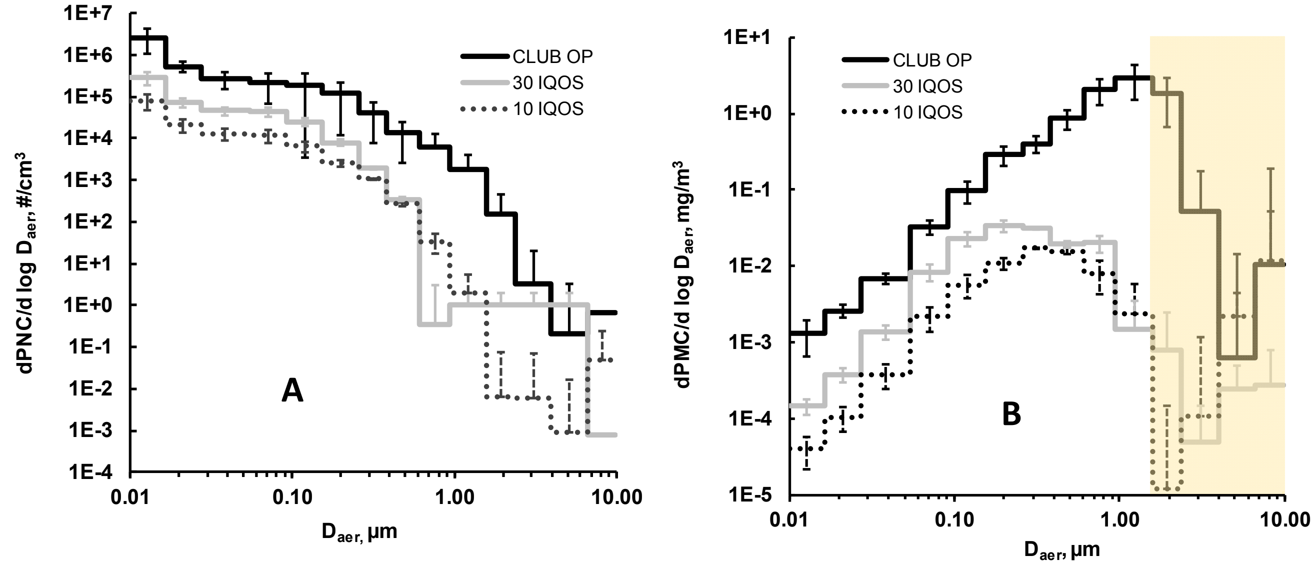
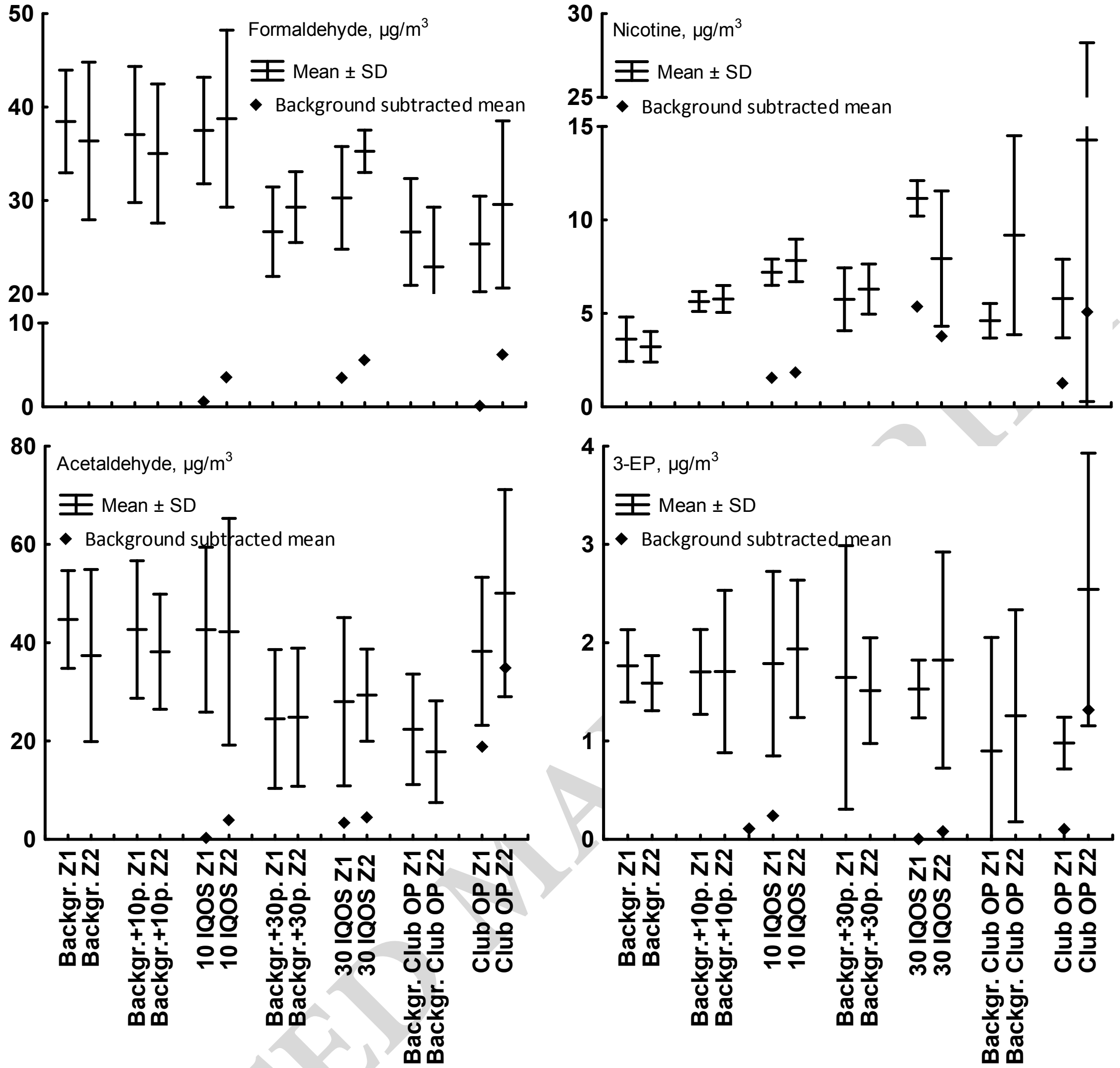


Fig.3.

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt



541
542
543
544
545
546 **Fig.4.**
547
548

Corresponding author. Tel. +370 682 14778
E-mail address: violeta.kauneliene@ktu.lt