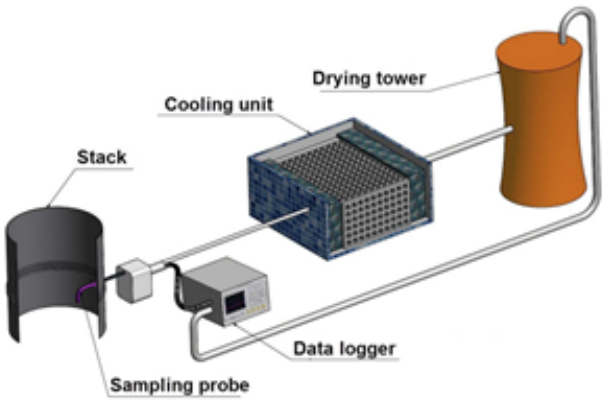

Figure 1. The measurement scheme for a flue gas analysis by gravimetric method.

conditions, following the gravimetric analysis itself. Isokinetic sampling is a sampling technique in which the velocity of gas in the nozzle of the sampling probe is the same as the velocity of gas in the flue-gas ducting [11]. The samples are collected on so-called flat filters.

For the measurement of particulate matter production, the analyzer Tecora (Fig. 1) can be used alongside the three-stage separation impactor ISOSTACK. Such devices allow for automatic isokinetic measurements of low, medium and high concentrations of particulate matters complying to norms EN 13284-1 and STN ISO 9096. The use of the aforementioned impactor enables to determine the particle size distribution: Concentration above 10 μm, concentration between 2.5 μm to 10 μm, and below 2.5 μm (PM2.5). The regulation of isokinetic condition for flue gas sampling is done via modifying the flue gas velocity. The flue gas velocity is measured by the Pitot tube. These measurement devices have to be regularly calibrated by authorized personnel.

3. Comparison of control methodology in EU countries

3.1. Procedures in Slovak republic

In Slovakia, Act no. 17/2007 Coll. presents procedures and intervals for regular inspection of boilers, heating systems and air conditioning systems (Table 4) [6]. These inspections must be carried out before the boiler room is put into operation, after each overhaul and reconstruction of the boiler. It must be also inspected when the type of fuel is changed, after the first year in operation, and a seasonal inspection is conducted at the beginning of each season.

Rated boiler output	Fuel	Regular inspection interval (year)	
		Family houses, apartment houses	Other buildings
20 – 30 kW	Fossil solid and liquid fuels other than natural gas	10	7
	Natural gas	15	12
	Biomass, biogas	12	15
30 – 100 kW	Fossil solid and liquid fuels other than natural gas	4	4
	Natural gas	6	6
	Biomass, biogas	10	10
From 100 kW	Fossil solid and liquid fuels other than natural gas	2	2
	Natural gas	3	3
	Biomass, biogas	6	6

Table 4. Frequency of regular inspections of boilers in Slovakia. [6]

3.2. Control procedures in Czech republic – "Semaphore/Stoplight" Methodology

In the Czech Republic, according to Act no. 172/2018 on air protection § 17 paragraph 1 entitled “Obligations of the stationary source operator”, states that the boiler operator is obliged by law to burn solely fuels that meet the requirements for fuel quality set by the manufacturer and corresponding legislation party. The method called "Semaphore", in translation "Stoplight", is intended to indicate the combustion of waste or contaminated fuel (CF) in stationary boilers with a rated output of up to 300 kW via ash analysis. The method measures 7 standard indicators: Pb, Cu, Zn, Cl, Sb, Sn, Ti [5].
The result of the analysis of each indicator is evaluated with three possible scenarios (depicted using a stoplight):

- Significantly exceeded value (A) - RED: The exceedance index of the given indicator is greater than 200%
- Suspicious value (B) - ORANGE: The exceedance index of a given indicator is greater than 100% and less than or equal to 200%.
- Permissible value (C) - GREEN: The exceedance index of the given indicator must be less than or equal to 100%

3.3. Control procedures in Nordic countries (Finland, Sweden and Denmark)

In Denmark, they regulate emissions utilizing the standard STN EN 305-5 [12]. Sweden uses its own established regulation directives such as the BFS 2006:12 for boilers up to 1025 MBtu/h,in which the concentrations of OGC and OC are regulated for boilers and pellet stoves. Furthermore, the Nordic Council has introduced an exceptional award "The Nordic Swan"

Device	Efficiency (%)	CO (mg/m³)	NOx (mg/m³)	OGC (mg/m³)	PM (mg/m³)
Stove	≥ 85 %	200/450	170/-	10/20	30/-
Boiler		100/225	170/-	5/5	25/-

Table 5. Exceptional German award "The Blue Angle" (at 12% O2, normal load / part load).

for meeting very strict CO, NO_2, OGC and dust emission limits for all manufacturers and suppliers of manual and automatic boilers within the Scandinavian countries [12] [2]. Boilers are categorized (1) based on type of heating - primary and secondary,(2) according to the loading method - manual and automatic, and (3) according to the rated output - up to 170 MBtu/h, from 170 to 510 MBtu/h and from 510 MBtu/h.

3.4. Fuel control

Decree no. 228/2014 Coll., introduced by the Slovak Ministry of Environment, sets requirements for the quality of fuels and their operational records. The decree sets limits on the content of sulfur, water and ash. For each type of fuel, it defines the procedures for the formation of bulk samples (STN SIO 5069-1 for brown coal), and the creation of samples for general analysis (STN 44 1314). Additionally, it drives the official form which records the amount of solid fuel sold [4] [14].

3.5. Exceptional awards from Germany

German energy agencies award prizes to boiler suppliers once in a while after meeting strict emission limits. For example, the "The Blue Angle" award is an exceptional award from the German Federal Environmental Agency intended for pellet stoves and boilers. Specific limits are shown in table 5 [12].

4. Proposal of control methodology

4.1. Proposal of a new methodology for the control of small heating devices in Slovakia

The integration of new Ecodesign requirements over the coming years will eliminate the operation of Class 1 and 2 boilers in Slovakia in early 2022. Basic operational control will consist of efficiency, particulate matter concentration, OGC, CO, CO2 and NOx measurements. The ash is sampled and a chemical analysis is made to determine combustion of unsuitable fuel. Additionally, it recommends measurements of smoke particles and its opacity [18].

The aim of this work is to design a theoretical model of heating in the future. This aim will be achieved by using previous knowledge about various methodologies of managing small heat devices abroad, in the introduction of new equipment and decommissioning of older, already incompatible, equipment. It is also visioned to introduce stricter measures to control flue gases and emissions, which are a by-product of heating. The control of airborne substances and the reduction of the use of incorrect / unsuitable fuel will be the focus conditions for improving the ecological, environmental and technical aspects of heating in the near future.

Fuel type	Own heating		Central heating	
	Proportion (%)	number of households	Proportion (%)	number of households
Wood	35	438	35	438
Black coal	5	62	5	62
Brown coal	10	125	10	125
Natural gas	50	625	50	625

Table 6. Distribution of fuel types between inhabitants of the mathematical model

4.2. Mathematical model of heating in Slovakia

In order to anticipate and evaluate the positive effects of the implementation of the proposed boiler control methodology in Slovakia, a mathematical heating model was created for a "town" with 10,000 inhabitants, which evaluates the savings in emissions and energy per year. It is assumed that 50% of the population lives in family houses (self-heating) and 50% in apartment buildings (central heating). Based on the professional experience of the authors, the distribution of fuels is assumed as presented in table 6.

The values of emissions per kWh of burnt wood were evaluated by a Slovak study [9]. The specific energies of fuel were chosen at 15 MJ/kg for wood and coal and 22.7 MJ/kg for gas [3]. According to a Slovak project carried out in 2018, a sample of 1549 households assessed the average wood consumption per year (8.7 tonnes/household), where energy consumption is based on 366 MJ/day/household.The apartment buildings in the model have 64 apartments, where the energy consumption is 309MWh per year, specifically 72.42 MJ / day / household [7].

It has been estimated that up to 56% of households use obsolete and unmaintained boilers, stoves and fireplaces, which produce a high percentage of emissions [17]. The mathematical model also assumes a new division of boilers in operation - class 3 would be used by 20% of the population, class 4 by 40% and class 5 by 40% of the population.

4.3. The results of analysis

Self heating in family houses recorded energy savings of 60.4% and 62.5% less emissions per year. Apartment

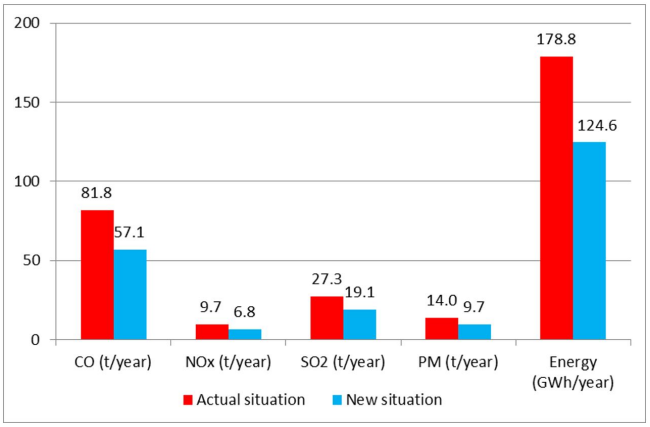

Figure 2. Evaluation of the results of a mathematical model for the population of 10,000.

buildings (central heating) recorded 43.8% energy savings and 49.9% less emissions per year. The largest decrease in the emission substance was TZL (by 55.3% and 52.0%) for both cases.

5. Conclusion

At present, the situation in Slovakia is insufficient in terms of citizens' knowledge of the correct way of heating, cleaning boilers / other heating equipment and their correct maintenance. There are cases when residents do not have the necessary knowledge on how to properly burn a particular fuel, and this often results in a state where a very unsuitable fuel is burned, for which a particular boiler is not designed and damages the particular boiler and the air. Mandatory inspections of heating systems are ignored and, as a result, old boilers and stoves, which should have been taken out of service a long time ago, are often used for many years there on.

The results, which result from the mathematical model, suggest an average improvement of 30% in air quality, which has a positive effect on both the exterior and interior of households, as the excretion of harmful substances during heating is significantly reduced. An important conclusion is more than 30% energy savings, which represents significant fuel savings. It can be assumed that the implementation of these incentives and the reduction in unsuitable fuels would result in a significant improvement in air quality and thus in the overall well-being of humans.

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