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A study on AC efficiency installations on articulated busses

Elisabeta Spunei, Ion Piroi, Florina Piroi

Air conditioning (AC) installed on vehicles must insure passenger comfort no matter the year season. To this end we make a series of measurements and readings of the interior temperature of vehicles with such AC installations. This work presents a study on the AC efficiency on public transportation vehicles, namely articulated busses. Our study shows that the AC appliances installed on the examined busses were not able to ensure the temperature assumed by the AC contractors. We propose that, for public transportation, AC installations should be sized accordingly to the vehicle's interior volume and to the transportation's body thermic insulation.

***Keywords**: functional efficiency, optimal temperature, measurement, thermic comfort*

1. Introduction

To ensure passenger comfort, public transportation vehicles are equipped with air conditioning installations (ACs). The choice of an appropriate AC is based on the volume of air that must be cooled down or warmed up and on the thermic isolation system of the vehicle carosserie.

The type of the cooling agent that is used in the AC has a determining impact on the AC's performances [1]. In certain situations, water is used instead of a refrigerant. In such cases, artificial intelligence algorithms are used to monitor and control the cooling system, which allows for a 39.8% reduction in energy consumption [2]. Using water as an AC coolant in countries with a temperate climate means that the water may freeze during the cold seasons, during rest periods. Methods for improving the AC energy consumption efficiency by monitoring the heating curves may use programmable logic controller (PLC) [3] or fuzzy based intelligent control systems [4].

The speed and direction of the air that is released by AC's air disperser has a high impact on the passenger comfort in a public transportation vehicle (and not only). The optimal air release speed for a given enclosure has been found to be of

4m/s [5]. For a higher passenger comfort it is recommended that the air flux released by the AC installation is directed towards the room walls and ceiling. Thus are avoided air currents towards passengers while ensuring a uniform working volume cooling.

The AC installations on public transportation vehicles are designed such that in the cold seasons they can heat the vehicle's interior. During the hot seasons, the difference between the outer and the interior air temperature is, on average, of 20°C (40°C outside temperature vs. 20°C inside temperature), while during the cold season, the temperature difference is of 32°C, on average (20°C inside temperature vs. -12°C outside temperature). Thus, an AC installation designed for heating during cold seasons will use only 60% of its power to cool the same space during the hot seasons.

Considering busses, using the heat of the exhaust gases can lead to a fuel reduction of 4500kg/year [6].

2. Determining the air conditioning installation power for an articulated bus

To determine the power of an AC installation we compute the necessary power to heat the same space during the cold season. The computation is done starting from the STAS SR 1907-1:1997 regulatory standard [7, 8]. The computation must establish the heat demand, Q per time unit, to heat a given volume of air.

$$Q = Q_T \cdot \left(1 + \frac{\sum A}{100}\right) + Q_I \,, \tag{1}$$

where: Q_T is the thermic flux ceded by transmission through space delimiters (e.g. bus carosserie) to the exterior; Q_I is the heat demand per time unit to heat the air entering the interior space from the outer temperature to the pre-defined interior temperature; $\sum A$ is the thermic flux additional to the ceded one, Q_T.

The transmission ceded thermic flux Q_T is:

$$Q_T = Q_e + Q_p \,, \tag{2}$$

where: Q_e is the thermic flux transmitted through the surfaces brushed by air on both sides, and Q_p is the thermic flux that is transmitted through surfaces in contact with the earth. The formula shown in [7, 8] refer to building types that are classified by age and insulation as:

- New buildings: 45÷60 W/m^2;
- Buildings older than 15 years: 70÷90 W/m^2;
- Old buildings that were constructed without following the regulations on thermic insulation: 120 W/m^2.

To determine the exact heat need for buildings we recommend using the Radia 3 software package [9].

Knowing the surface, S, of the space to heat, using the specific capacity Q_S, we find the necessary power, Q, to ensure the required temperature level:

$$Q = Q_S \cdot S\,, \qquad (3)$$

If for buildings the maximum specific capacity is of 120 W/m^2, for busses, AC manufacturers use proprietary software specific to the AC installation, such that specific capacity can reach high values between 780 W/m^2 and 800 W/m^2 [10]. These values reflect the fact that, for busses, the ceiling, side walls and the flooring do not have proper insulation.

3. Case study

For our case study we considered a bus 18.6 m long, 2.4 m wide, and 2.5 m tall. The bus AC has two air-blowers with 380 W unitary power, that is 1,297 BTU/h. This installation does not ensure the cooling requirements for the driver's space of a bus with the size specifications mentioned above.

To determine the bus interior temperature we took temperature measurements during the summer season on a 11 km route length between two points of interest in Resita ("Gara" and "Muncitoresc"). The outer temperature was of 32°C. We used the following temperature measuring instruments:

- TESTMATE 215 with a ± 0,1°C measurement error;
- AXIO, AX588 MET with a ± 1°C measurement error.

We recorded the interior temperature while the bus was between stations at the following time points:

- before the bus doors opened;
- before the bus doors closed for leaving a station.

The measuring instruments were placed:

- in the second bus part (2nd compartment), on the compartment axis, on the door position;
- on the bus axis, within the articulation;
- in the first bus part (1st compartment) at the thermally isolated engine location.

Table 1 presents the measurements taken when the bus was in the bus station and at half distance between the stations, for one direction. The rows marked with yellow contain the measurements in the bus stations. The unmarked rows show the temperature measurements taken while the bus was between two stations. The bus stations are numbered from 1 to 30 for one direction, and 31 to 58 for the return direction.

Table 1.

ID.	Bus station nr.	°C in the 2nd compartment		Articulation °C		°C in the 1st compartment (Engine compartment) (5)
		Door, before station stop (1)	Door open (2)	Before bus stop (3)	In bus stop (4)	
1.	1	37	35.4	34	34.0	38.4
2.	2	37.0	37.0	34.0	34.0	38.4
3.		38	-	34	-	-
4.	3	38	36.7	35	34	38.4
5.		37.5	-	34	-	-
6.	4	38	35.1	35	32	38.4
7.		36.6	-	33	-	-
8.	5	37.7	36.8	35	35	38.4
9.		37.7	-	35	-	-
10	6	37.8	37.1	34	34	38.5
11		37.5	-	34	-	-
12	7	37.8	37.4	34	33	38.5
13		37.2	-	33	-	-
14	8	37.7	35.3	34	33	38.5
15		37.7	-	34	-	-
16	9	37.1	35.4	34	34	39
17		36.7	-	34	-	-
18	10	36.8	33.5	34	32	39
19		36	-	33	-	-
20	11	37.2	34.1	34	32	39
21		36.5	-	34	-	-

22	12	36.2	34	34	33	39
23		36.7	-	34	-	-
24	13	37.5	36.2	34	34	39
25		37.4	-	34	-	-
26	14	38	35.4	34	32	38.6
27		36.7	-	33	-	-
28	15	37.6	37.2	34	34	38.7
29		38.4	-	34	-	-
30	16	38.5	36.8	34	34	38.8
31	17	37.5	38	33	34	38.8
32		38.2	-	34	-	-
33	18	38.6	37.9	34	34	38.9
34		38.3	-	34	-	-
35	19	38.8	37.1	34	33	39
36		37.7	-	33	-	-
37	20	38.2	37.3	34	34	39.1
38		38.4	-	34	-	-
39	21	38.5	37.5	34	33	39.3
40		37.6	-	33	-	-
41	22	37.9	37.8	33	33	39.4
42		37.8	-	33	-	-
43	23	38.2	34.7	33	32	39.5
44		36.8	-	32	-	-
45	24	37.4	33.1	32	31	39.6
46		36	-	31	-	-
47	25	38.1	37.2	33	33	39.6
48		37.7	-	33	-	-

49	26	38.2	37.3	33	33	39.6
50		37		33		
51	27	37.7	37.4	32	32	39.6
52		38.1		33		
53	28	37.8	37.7	33	33	39.7
54		37.4		32		
55	29	37.7	37	33	32	39.8
56		37.1		32		
57	30	38	36.5	32	32	39.9
58	31	38	37	33	33	39.9

Figure 1 show the temperature variation recorded on the direct tour, while Figure 2 shows the temperature variations on the retour route.

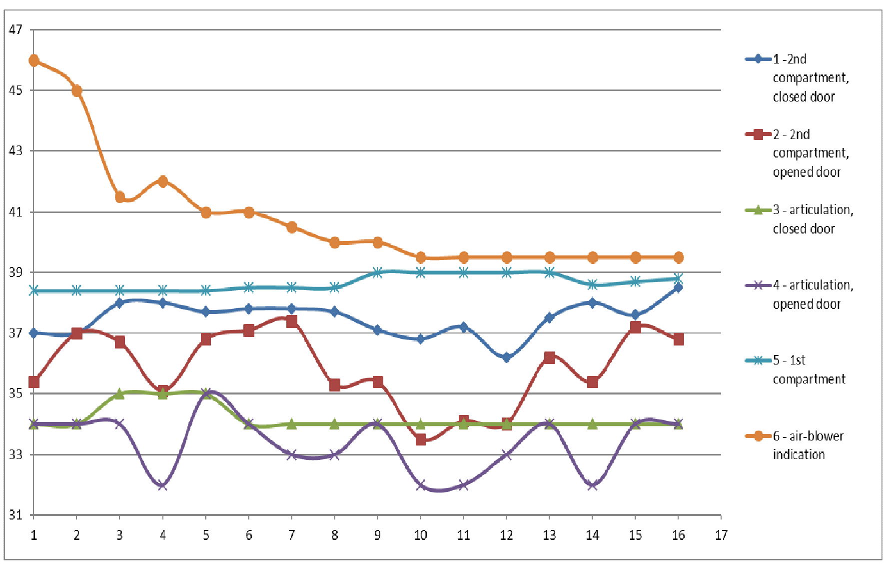

Figure 1. Temperature variation on the direct route (bus stops 1-30).

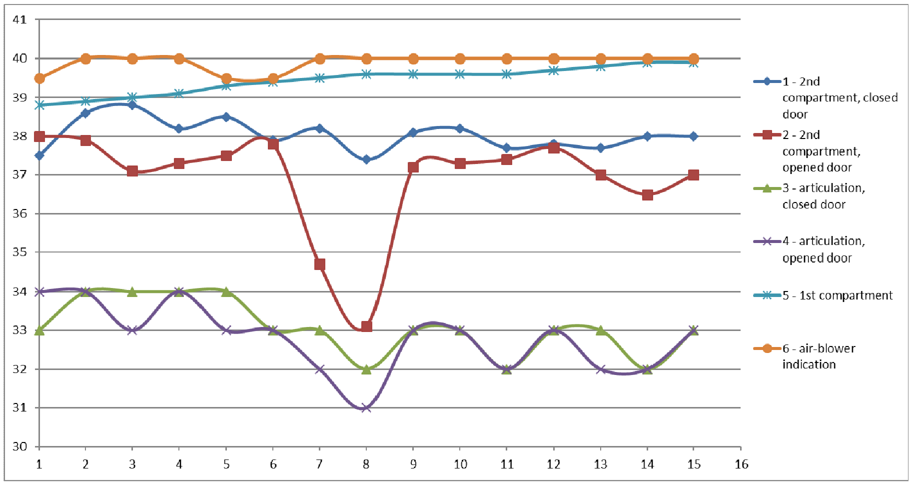

Figure 2. Temperature variation on the retour route (bus stops 31-58).

Collecting the temperature measurements in the 2nd compartment, on the articulation, we obtain the results shown in Figure 3 for the direct route, and Figure 4 for the retour route. We can observe the temperature variations before the doors open and before the bus stops in the bus station, as well as those when the door is open, before the bus leaves the station.

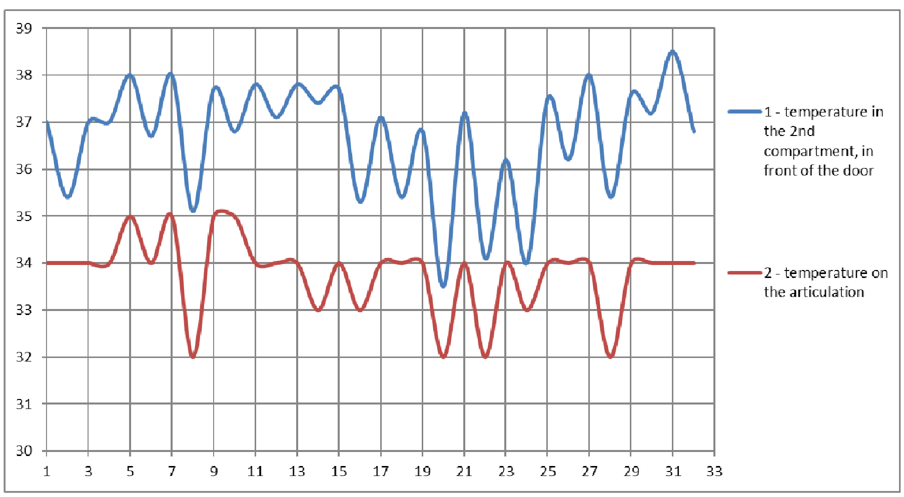

Figure 3. Temperature variation graph for closed and opened doors measurements on the direct route.

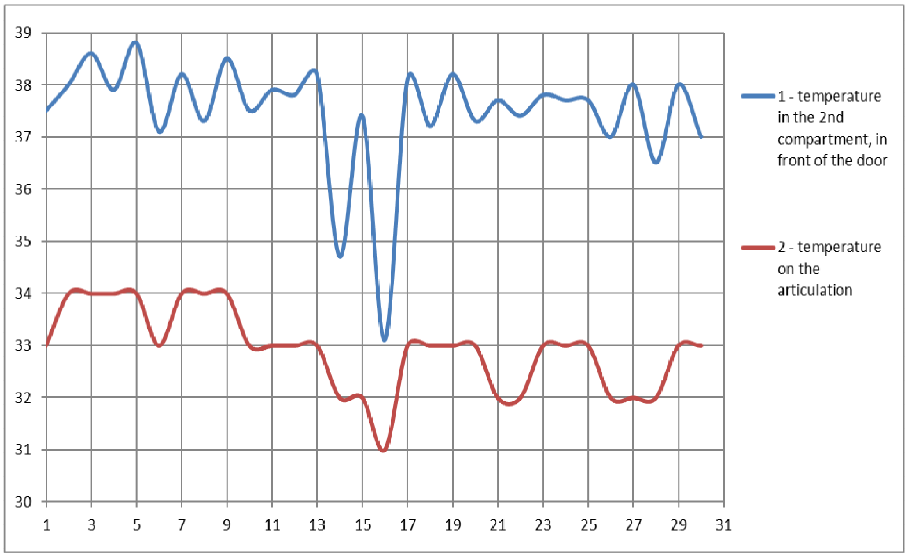

Figure 4. Temperature variation graph for closed and opened doors measurements on the retour route.

4. Conclusion

Our measurements concluded that the air conditioning installation with which the bus in our case study is equipped cannot ensure the required microclimate for the respective season. The installed air-blower could not ensure the cooling of its own structure.

The values presented in Table 1, Figures 1 and 2 show that the inside temperatures were, in all measurement points, higher than the required temperature (lower than 29°C). In addition, the outer temperature on the day the measurements were taken was of 32°C, and not 40°C as in high summer.

In the bus's first compartment, below which the bus engine is located, the measured temperatures show small variations around 39°C, which were higher than the outer temperature.

It is also easy to observe, from Table 1 and Figures 1 and 2 that the temperature measured on the axis close to the bus doors are lower when the doors are open, which shows that the outer air, entering the bus, actually cools down the air inside the bus, which is contrary to the desired cooling effect of the AC (compare curves 2 and 4 with curves 1 and 3). This can be seen even more clearly in Figures 3 and 4 where the vertical grid lines mark the temperatures measured during at bus stops (odd numbers), before the doors open. The measured temperature after the doors open drops by three degrees (even numbers), which shows that the bus is actually ventilated using the outside air.

The temperature measurements are also influenced by the buildings along the bus route, buildings that shade the bus, trees, wind, and the city river breeze (the route follows for some length the river in the city). This, again, is a proof of the very low efficiency of the AC installed on the bus.

The measurements were done without bus passengers, which would have caused even higher temperature measurements.

Our conclusion and recommendation to the town city hall is to install a different air conditioning appliance, with a power of at least 35 kW, and perform a new set of measurements for the new AC, both during the hot and cold seasons.

References

[1] Schulze C., Raabe G., Tegethoff W., Koehler J., Transient evaluation of a city bus air conditioning system with R-445A as drop-in - From the molecules to the system, *InternationaL Journal of Thermal Sciences*, 96, pp. 355-361.

[2] Cheng C.C., Lee D., Artificial Intelligence Assisted Heating Ventilation and Air Conditioning Control and the Unmet Demand for Sensors: Part 2. Prior Information Notice (PIN) Sensor Design and Simulation Results, *Sensors,* 19(5), 2019.

[3] Rață G., Rață M., *Temperature Control Solution with PLC*, 9th International Conference and Exposition on Electrical and Power Engineering (EPE), 20-22 Oct., 2016, Iași, România, pp. 571-575.

[4] Tirian G.O., Gheorghiu C.A., Heput T., Chioncel C.P., *New solutions to control water flow in the secondary cooling*, 17th IEEE International Symposium on Computational Intelligence and Informatics (CINTI), 17-19 Nov., 2016, Budapest, Hungary, pp. 363-368.

[5] Ji W.H., Wang H.H., Du T., Zhang Z.L., Parametric study on a wall-mounted attached ventilation system for night cooling with different supply air conditions, *Renewable Energy*, 143, pp. 1865-1876.

[6] Kurtulmus N., Bilgili M., Sahin B., Energy and exergy analysis of a vapor absorption refrigeration system in an intercity bus application, *Journal of Thermal Engineering*, 5(4), pp.355-371.

[7] *Instalații de încălzire. Necesarul de căldură de calcul. Prescripţii de calcul*, STAS SR 1907-1:1997.

[8] Piroi I., Cziple F., Pomoja F., *Conversia energieie regenerabile a apei, pământului și deșeurilor organice*, Editura Eftimie Murgu, Reșița, 2010.

[9] *Calcul necesar termic - pierderi de caldura. Dimensionare radiatoare, centrala, puffer*, http://calcul-termic.blogspot.com/2009/05/mici-modificari.html

[10] Mercedes-Benz, date tehnice, https://www.mercedes-benz-bus.com/ro_RO/models/citaro-ue/facts/technical-data.html.

Addresses:

- Lect. Dr. Eng. Elisabeta Spunei, “Eftimie Murgu” University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, e.spunei@uem.ro
- Prof. Dr. Eng. Ion Piroi, “Eftimie Murgu” University of Reşiţa, Piaţa Traian Vuia, nr. 1-4, 320085, Reşiţa, i.piroi@uem.ro
- Dr. tech. Florina Piroi, Institute of Information Systems Engineering, TU Wien, Favoritenstrasse 9-11, 1040, Vienna, Austria, florina.piroi@tuwien.ac.at