PAPER ID: 0366
DOI: 10.18462/iir.compr.2021.0366

FIELD MEASUREMENT ON ROOFTOP CONDENSING UNIT BEFORE AND AFTER RECONSTRUCTION

Peter Tomlein
Slovak Association for Cooling, Airconditioning and heat Pumps
SZ CHKT, Šamorín, 93101, Slovak Republic, szchkt@szchkt.org

ABSTRACT

Packaged rooftops cooling only (hereinafter referred to as rooftop) equipped with AC fans motors on condensing unit can be retrofitted to fans with EC motors. Economy of fan retrofits depends on operation time, which is short in cooling mode. Reconstruction of rooftops from cooling-only to heating-also mode enables longer operation time and better retrofit and reconstruction economy. Methodology for heat balance calculation in cooling and heating mode can differ. Monthly method according to STN EN ISO 13790 and hourly method according to EN ISO 52016-1 were used to calculate thermal balances of the building. Importance of the new hourly method is demonstrated in comparison with the commonly used monthly method. Efficiency and operation time of the heat pump depended on on/off compressors, which operation range had to be limited. Field measurement showed higher efficiency after fans retrofit. Efficiency of reconstruction from cooling-only to heating-also mode depends on the extent of reconstruction. Field measurement showed a need for precautions against possibly risky compressor operation.

Keywords: Field measurement, fans, electric motor, on/off compressor, rooftop cooling only

1. INTRODUCTION

Originally outdoor packaged cooling only rooftop (hereinafter referred to as rooftop) units designed with fans with AC motors can be retrofitted to fans with EC motors. EC motors contrary to AC motors with current regulator on the baser of condensing pressure can reach more as 30% energy savings and lower noise (Grundmann, 2017). Important factor is the price of EC motor, which is lower in comparison to AC motor with frequency converter. With still raising requirements on energy efficiency are new types of EC motors in new products demanded.
Retrofit or exchange of fan and its control on existing cooling circuit influences also operation of cooling circuit, which depends mostly on compressor control. Compressor on/off is not able fully use possibilities of floating condensing temperature dependent on outside temperature. Influence of fan retrofit on energetical efficiency of cooling circuit is important, because it can be energetically and economically more significant as savings coming only from replacement of AC for EC motor on condenser fans (Vavro, 2019).
Economy of fan retrofit depends mostly on lengths of operation time, number of fans and size of the rooftop. Prolonging of operation time is possible by reconstruction of cooling circuit on reversible, with also the heating possibility. Possibility of prolonging of operation time is compared according energy demand calculated using monthly method on the base of average monthly temperature. The result is the need for heating or cooling. Hourly method not only calculates energy demand with higher accuracy, but also differentiates, whether heating or cooling is required. Hourly method is more convenient for heat pumps, because in calculation specific COP and EER values are used for every hour. COP and EER used for every hour depend on extent of load and source temperature. Demand for heating and cooling calculated by hourly method is up to 20 % lower as demand calculated by monthly method a that is why the economy of rooftop retrofit or reconstruction is less supported.
Due to that rooftops are located outside with high temperature differences, there is a risk of refrigerant migration from warmer to colder components and during start or reversion of cooling circuit. Migration of refrigerant can

cause during the compressor start suction of wet refrigerant and damage or complete destruction of components determined on vapor compression. Assessment of migration, penetration of wet refrigerant into scroll compressor is aimed on rooftops originally designed only for cooling and later reconstructed also for heating.

2. FIELD MEASURMENT

2.1 Choice of cooling equipment

Rooftop accessible for measuring appliances was chosen for fan retrofit. Multipurpose compact ventilation unit with plate recuperation for heat recovery was located on the roof of administration building. It consists from components for air transport and treating. It is designated for ventilation with heating and cooling air for conference room. Ventilation unit with recuperation carries out:

1. Suction of outside air with one stage filtration, heat recovery, heating, cooling and transport of treated air to conference room,
2. Suction of polluted air with one stage filtration, heat recovery and discharge to outside.

Figure 1 Cooling equipment was a part of ventilation unit, which treated air from conference hall

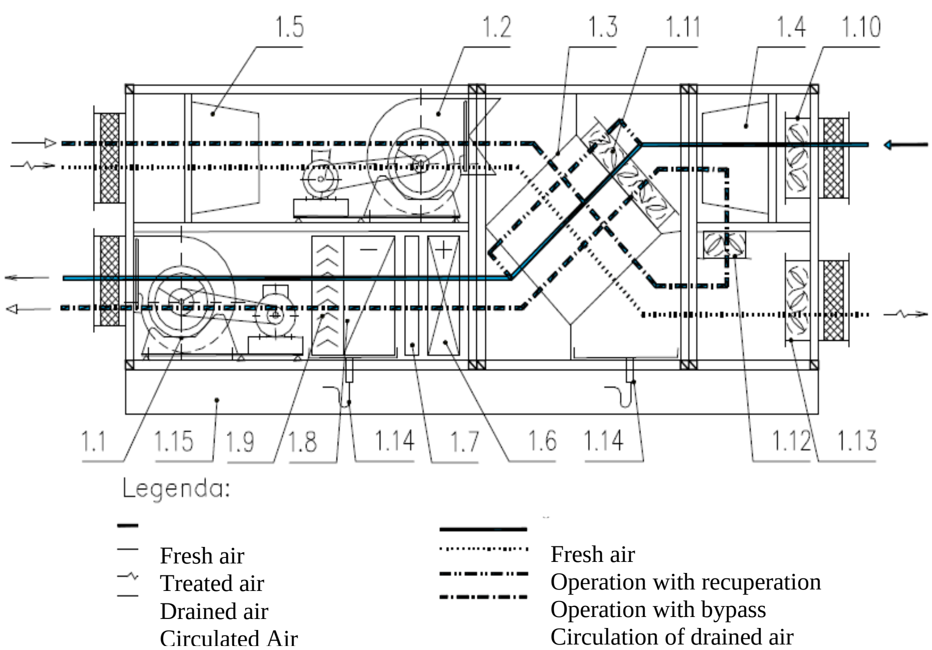


Figure 2 Configuration of ventilation unit BKL KD with the routes of air. 1.1 fan of inlet air 1.2 fan of outlet air 1.3 panel of recuperation 1.4 bag filter 1.5 bag filter 1.6 heater 1.7 frame of antifreeze protection 1.8 chiller / evaporator 1.9 eliminator of water drops 1.10 flap of fresh air 1.11 flap of bypass 1.12 flap of circulated air 1.13 flap of outlet air 1.14 drainage of condense – siphon 1.15 basic frame

Figure 3 Condensing unit Clivet MSAT 122 on the left with AC fan FB056-8EA 4F.A4P and current regulator according to condensing pressure substituted on the right by EC fan ZN0566ILBDV5P4

Fan retrofit required minimum technical changes in installation. Both AC and EC speed regulated motors contrary to on/off save energy exponentially at lowering of condensing pressure. Fixing of fan with EC motor differs from AC fan used up to now. Body of EC fan is designed as diffusor. Different is also fixing of pressure sensor into cooling circuit.

2.2 Fan retrofit

Measurement on condensing unit were carried out in two phases:

1. On original 2 one phases fans type FB056-8EA 4F.A4P with AC motors.
2. On new EC fans type ZN0566ILBDV5P4 with EC motors

Table 1 Comparison of both fans' parameters

Type of Fan	Flow $[m^3.h^{-1}]$	Transport pressure [Pa]	Power [W]	Noise on suction side [dB]	Speed $[min^{-1}]$	Current load [A]	Voltage
FB056-8EA 4F.A4P (orig. AC)	3800	30	220	65	680	1	1~ 230V 50Hz
ZN0566ILBDV5P4 (substitution EC)	3800	30	83	53	584	0,39	1~ 230V 50Hz

The heat load in conference hall, due to temperature outside conditions in April 2019 was simulated using moveable electric heaters. Eight heaters were used with total power 16 kW. Required temperature in conference room was set on 19,5 °C. After two hours the conference room was warm enough and cooling circuit was activated. After the cooling circuit was switched on recorded data could be followed on web page ClimaCheck with the accuracy (Berglof, 2019):

- Pressures ± 1 %
- Temperatures ± 0,5 K
- Power ± 2 %

ClimaCheck Performance Analyzer evaluates data in real time and calculates derived parameters. ClimaCheck was connected to internet, so all participant of measurement could follow history and development of cooling circuit parameters in real time on their computers.

Figure 4 Appliance PA PRO II measured 8 temperatures, two pressures and electric parameters of compressor and condenser fan electric motors with power calculation by two appliances PowerScout

For comparison AC and EC fans was important to measure at the same or similar conditions. We have chosen the nearest comparable results at the evaporation temperatures with AC fan in the range from -1,5 to -1,7 and with EC fan from -2 to -2,5 °C at outside temperature 25,5 °C. These nearest comparable results from cooling circuit measuring with AC and EC fans were averaged.

In case of usage EC fan condensing temperature was maintained, but evaporating temperature has decreased from -1,55 to -2,45 °C. Subcooling decreased significantly from 10,98 to 2,5 K superheating slightly increased from 10,5 to 10,79 K. It was caused by refrigerant leakage.

Measured fan power differences were high. It had impact on SPF of EC fan motor, which was more as 2,5 times lower as SPF – specific fan power of AC motor. SPF decreased from 208,4 to 78,6 W.s.m-3 (table 2). According to values reached from Modbus SPF of EC fan motor would be even lower.

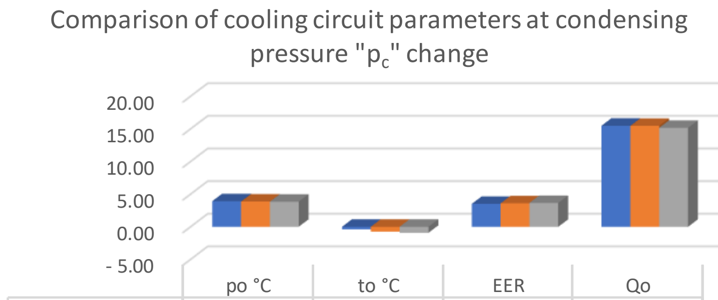
Table 2 Comparison of SFP and fans efficiencies

Type of fan	Flow $[m^3 . h^{-1}]$	Specific fan power SFP [W.s. m^{-3}]	Class SFP [-]	Transport efficiency [-]
FB056-8EA 4F.A4P (original AC)	1,05556	208,42105	1	0,143939
ZN0566ILBDV5P4 (substitution EC)	1,05556	78,631579	1	0,381526

Figure 5 Measurement using Modbus protocol presented about 30 % lower fans power as multiplication of measured values as voltage, current and power factor. Using Modbus protocol next values were read as fan speed, currents, voltage, power factor, ...

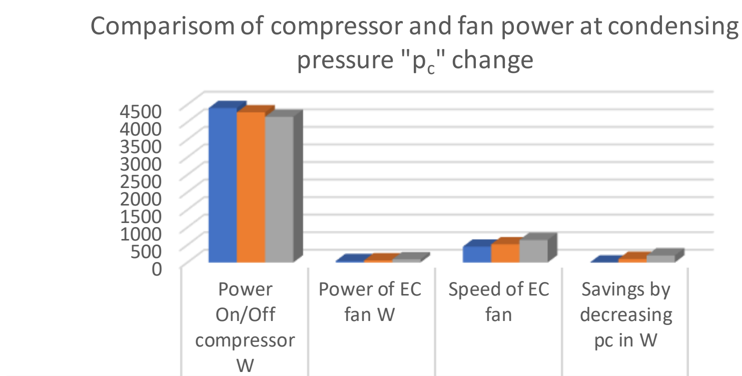
2.3 Influence of condensing pressure change

Measuring was on three pressure levels, from which the highest was the highest possible pressure level. Due to use on/off compressor together with increasing of condensing pressure, also evaporating pressure was increasing. slightly cooling performance, compressor power, fan speed and power, but EER was decreasing. While compressor power was in the range 4150-4400 W, fan power in the range 40-90 W. Total difference was approximately 200 W at condensing pressure change of 1 bar, Savings could be higher, if evaporating temperature will be not decreasing together with condensing temperature. It was not possible to reach with on/off compressors and TEV.



	po °C	to °C	EER	Qo
At pc = 17.84 bar	3.92	- 0.38	3.51	15.48
At pc = 17.67 bar	3.87	- 0.74	3.60	15.47
At pc = 16.92 bar	3.84	- 0.92	3.65	15.16

Figure 6 Adjusting of condensing pressure on the left. On the right graph and table decreasing condensing pressure at the approximately same outside temperature 25,5+0,5°C also evaporating pressure, temperature and cooling performance have decreased and EER has increased



	Power On/Off compressor W	Power of EC fan W	Speed of EC fan	Savings by decreasing pc in W
At pc = 17.84 bar	4400	40	450	0
At pc = 17.67 bar	4280	60	518	100
At pc = 16.92 bar	4150	90	640	200

Figure 7 Decreasing condensing pressure at the approximately same outside temperature 25,5+0,5°C caused decreasing of compressor power and EC fan power and speed have increased

2.4 Discussion to fan retrofit

Fan consumption of electricity difference in solved case is considerable, but in comparison to total electricity consumption of refrigeration equipment less important. Savings on fan electricity consumption depends on operation time of cooling circuit. Payback of retrofit costs only from savings o electricity consumption of fans at relatively short operation time of cooling circuit only in summertime, can be too long. In case of electricity savings up to 25 €/year and retrofit costs up to 2500 € up to 20 years.

Added benefit of retrofit to EC fan is possibility of increasing the fan performance in case of need to compensate increasing summer temperatures extremes. It is important to remind, that older fans already are not coincident with requirements of Eco-design.

If fan with AC motor is on the end of its life it is right practice to install EC fan, if it is technically possible. In such a case proved savings on electricity taking into consideration only the cost difference on exchange of EC for AC fan, payback is getting significantly shorter.

In such a case about fan retrofit will not decide economy, but the necessity of fan exchange or complete equipment. Energetical, economic and ecological analysis of retrofit effectivity depends mostly on size of equipment, number of fans and their control, extent of retrofit (EEV, compressor speed control, …), operation time per year. Prolonging of operation time is possible by reconstruction of cooling circuit on reversible, working in both cooling and heating mode.

2.5 Experiences from rooftop reconstruction

Reconstruction of rooftops from cooling-only to heating- also mode enables longer operation time and better retrofit economy. There was an effort of rooftop reconstruction on heat pump. Result was higher risk of refrigerant migration and penetration of liquid refrigerant into on/off scroll compressor. Before reconstruction there were not recorded significant high leaks of refrigerant, neither refrigerant migration causing compressor destruction. Cooling circuit after reconstruction in operation was characterized by repeated leakages and numerous destructions of scroll compressor spirals. Leakages had nothing to do with scroll destruction.

Leakages were caused for example by burst pipe and were related to tubes dimensioning, dilatation, distribution and again merging into one tube before and after heat exchangers and common fixing of both compressors on basic plate. Sizes of heat exchangers remained the same. Inner heat exchanger with smaller volume as the outside heat exchanger. Migration of refrigerant is related to higher charge of refrigerant without receiver of liquid refrigerant, with temperature changes also when compressors are out of operation and during reversion of cooling circuit before and after defrosting. Directly the migration of refrigerant was not proved. Measurement demonstrated suction and compressor temperature decreasing after compressor start.

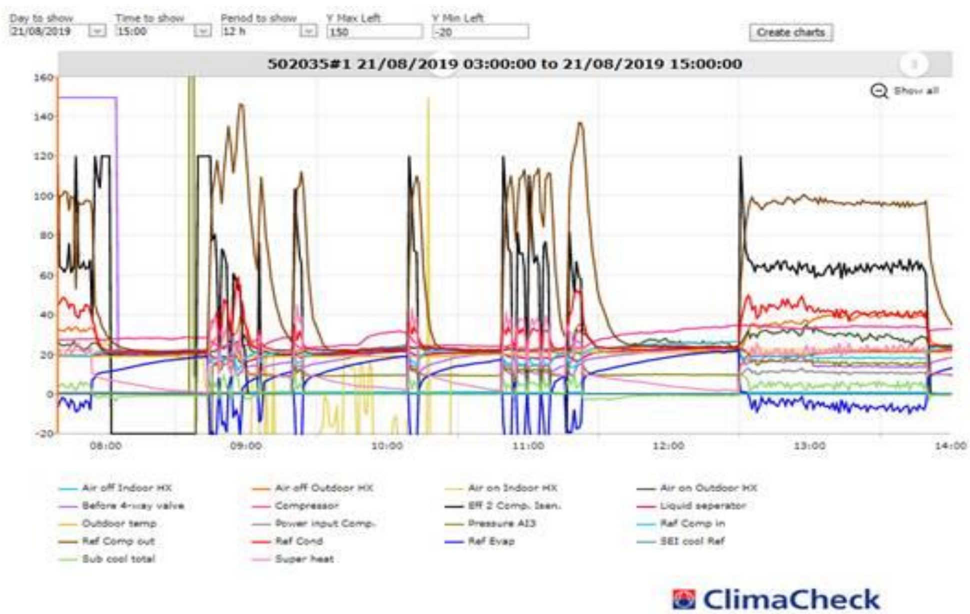


Figure 8 System in cooling mode with two compressors in operation is short cycling with discharge temperature over 140°C. Evaporation goes down well below -20°C. At 12:30 reached better operation conditions with one compressor in operation

Measurement in heating mode has demonstrated similar problems. Suction and compressor temperature after start on/off compressor decreased from 14°C to -6.6°C after compressor start but after 5 minutes it was already stabile at the level over 8°C. It can be a problem of liquid carry over. Most compressors allow this at start up - but in case of many start-ups after each other it as high-risk operation. Liquid return by decreased compressor discharge temperature has been proven. At compressor start there could be a liquid in accumulator boiling over. Such start would not have to be critical, if it occurs occasionally but the controls and expansion valve together with very poor evaporator performance would introduce a lot of stress on compressors. Evaporator had very low efficiency from start and the expansion valve cannot control superheating at low evaporation.

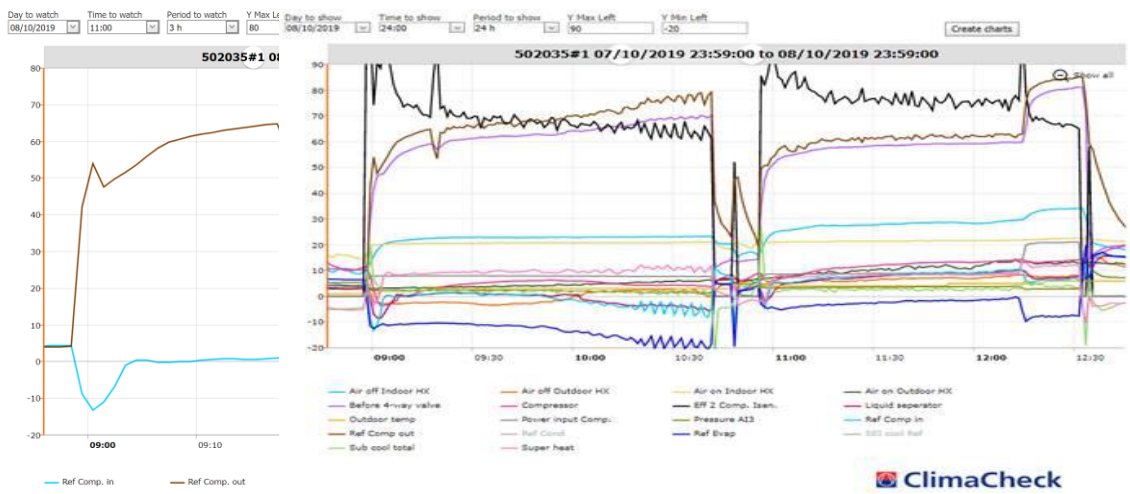


Figure 9 Left side suction and compressor temperature after start on/off compressor decreased in the heating mode. Right side with two periods operation. First period ended with possible frosting, or dirty in distributor tubes. Second period ended with both compressors running at lower evaporation temperature

Two periods operation - before 10:50 - stop due to too low suction pressure. After 11:00 operation again with only one compressor is better and after switching on the second compressor, high capacity caused very low evaporation and high condensing temperature. There was an indication that expansion valve and distributor had problems due to frosted evaporator at 10:15 and 12:15 when both compressors were running.

Compressor started at 8:58 and then there was liquid carry over at 9:00 - compressor discharge temperature is decreasing from 54 to 47 (9:01). There was likely some liquid entering the compressor due to discharge temperature decreased very quickly.

The evaporation was at 10:15 unacceptably low -20°C at part load during first stop below at 3°C ambient.

Expansion valve was hunting terrible at low evaporation (10:30). If it would continue longer it would be a risk for liquid carry over. Compressor was switched by low pressure control (10.40)

2.6 Discussion to rooftop reconstruction

Consistent reconstruction of rooftop able to work not only in cooling but also in heating mode is important. Reconstruction of rooftop with on/off compressors suitable for wet start in reversible cooling circuit requires right dimensioning of expansion valves, tubes, heat exchangers, right installation practice. In other case risks of limited or emergency operation as it is based on results from measurement are high. To get rooftop to normal operation in both modes obviously will be not possible without suitable conception and major redesign.

2.7 Hourly and monthly method - calculation of building energy demands

Methods used thermal balance of the building:

- monthly method according to STN EN ISO 13790
- hourly method according to EN ISO 52016-1

The heat source power is based on the external calculation temperature and the associated heat loss consisting of the passage of heat and ventilation. Climatic data were provided by Slovak hydrometeorology institute. Both the hourly and monthly methods are used to demonstrate the difference in the performance regime over the selected 4 days in each season. The theoretical required heat output is determined as the difference between heat loss and heat gain. The value of heat loss is calculated for each hour of the day and heat gains (indoor and solar) are evaluated by Simulation 2018 based on location, altitude, building orientation, used materials, house occupants and other factors. Heat accumulation is considered (Svoboda, 2018):

- in the building construction - the specific heat capacity, the thermal conductivity and the density of each layer of material are specified.
- room equipment - according to EN ISO 52016-1 standard value of 10 000 J / (m^2K) is assumed for common rooms - if the value is set to 0, the state for a completely empty room would be calculated.
- in the air.

Calculation in the software run in the "free float" mode, that means without the providing heat/cold from the source (the indoor air temperature therefore depends only on the boundary conditions). The output of the calculation is a protocol containing a graph of the resulting temperature in the room (reaction of the room) to the boundary conditions, which are mentioned heat gains, outdoor temperature and ventilation. The heat required to heat the mass of the room air is determined from the calorimetric equation.

2.8 Energy demands and energy intensity

The hourly method, an hourly step, allows more detailed access to a building requiring both heating and cooling. In the monthly calculation, it is also difficult to check the need for cooling in the months when it is still heating. The lowest value of primary energy consumption is demonstrated by the hourly calculation method. This principle is suitable for heat pumps as it more precisely considers the calculation with the corresponding COP in relation to the outside temperatures for each hour of the year. The COP is calculated per hour and depends on the load rate and temperature of the low potential heat source. The figure with comparison of energy demands in kWh/m^2 per year calculated by monthly and hourly method shows not only the lower energy requirements calculated by the hourly step, but also the cooling requirements in April, May, September, which remained hidden when using the monthly method.

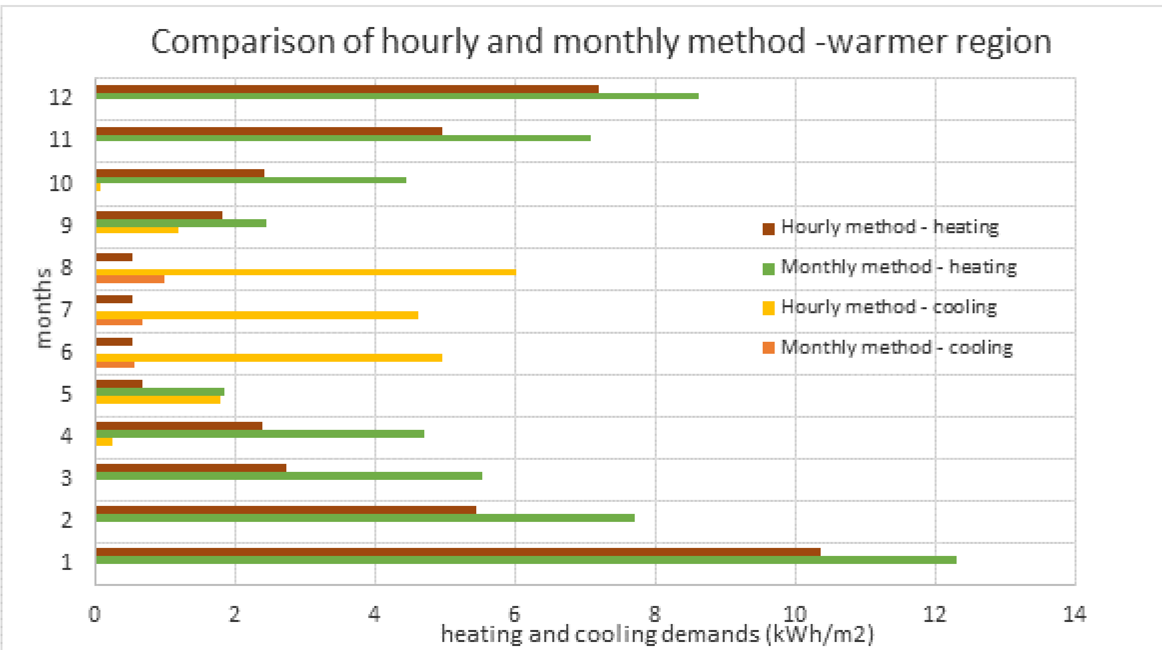


Figure 10 - Comparison of energy requirements in kWh/m^2 per year calculated by monthly and hourly method. The figure shows not only the lower energy demand calculated by the hourly step, but also the cooling demand in April, May, September, which remained hidden using the monthly method

Finally, usage of hourly method due to calculated lower energy demand and lower primary energy consumption has not sufficiently supported economy of the rooftop retrofit or reconstruction and even less as heat balance and energy intensity calculations using monthly method. The difference between hourly and monthly methods of calculating energy demands is significant up to 20 % (Stančíková, 2019) and the need of cooling monthly method cannot accurately describe.

1. CONCLUSIONS

Rooftop originally operated with fans with AC motors has been retrofitted to fans with EC motors. Field measurement proved higher efficiency after fans retrofit even with on/off compressors. Economy of fans retrofit depends on operation time, which in cooling mode is short.

Rooftop reconstruction from only cooling mode to also heating mode enables longer operation time and expected better retrofit economy. Success of reconstruction from only cooling mode to also heating mode depends on the possible extent of reconstruction. According to field measurement efficiency and operation time of heat pump depended on on/off compressors, which operation range had to be limited. Field measurement proved necessary precautions against possibly risky compressors operation.

Finally, usage of hourly method due to calculated lower energy demand and lower primary energy consumption has also not supported economy of the rooftop retrofit and reconstruction and even less as heat balance and energy intensity calculations using monthly method.

ACKNOWLEDGEMENTS

This work and experimental measurements were supported by Slovak University of Technology, Slovak Association for Cooling, Airconditioning and Heat Pumps, company Riservis, s.r.o. Bratislava and company Ziehl-Abegg s.r.o., Brno, which has provided the measuring with fans and fan regulation technique.

NOMENCLATURE

AC	electric motor driven by an alternating current	*COP*	Coefficient of performance
EC	electronically commutated direct current motor	*EER*	Energy efficiency ratio
p_k	pressure (kPa)	*SFP*	Specific fan power

REFERENCES

Berglof, K.: Performance monitoring of the energy with unbiased method. XVIII European conference, Polytechnico Di Milano, 6-7 June, 2019

Hogelink, J.: Building Energy related standards as have been published by CEN and ISO. KGH congress, Belgrade, 4-6. December, 2019

Svoboda Z. 2018. Simulace 2018: dle EN ISO 52016-1. URL: http://blog.kdata.cz/ stavebni-fyzika/article/simulace-2018-zcela-novy-vypocetni-model-podle-en-iso-52016-1/

Stančíková I., Tomlein P.: Heat Balances by using Heat Pumps and Fan Retrofit, KGH congress, Belgrade, 4-6. December 2019

Tomlein P. SZCHKT, 2016. Heat Pumps in Administration and Industry. ISBN 978–8089376–10-0

No. 324/2016 Z. z.: Amendment, Ministry of Transport, SR, to no. 555/2005 Z. z. on EPBD

Pogány Ľ.: Energetical efficiency of fans with air filtration. Diploma work. Supervisor Tomlein Peter, STU, SjF, ÚESZ, 2017

Vavro P.: Comparison of fans with AC and EC motors in rooftop operation. Diploma work. Supervisor Tomlein Peter, STU, SjF, ÚESZ, 2018

Grundmann R.: Elementary Fan Technology. Ziehl Abegg, 2017.

Maintenance manual: Ventilation unit with recuperation BKL-KD and air-cooled condensing unit

Fan select Ziehl Abegg and standard EN ISO 52016-1