# ANTHROPOGENIC HEAT FLUX IMPACT ON MESOSCALE ATMOSPHERIC PROCESSES

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# Abstract

The anthropogenic heat fluxes (AHF) above urbanized territories around the world very strongly affects mesoscale atmospheric processes.

AHF within the largest urban agglomerations of the world could be estimated by empirical assessment, based on the use of the most reliable data on the population and energy consumption of the urban economy of megacities.

Regional atmospheric advection significantly affects the intensity of the urban heat island, strengthening or weakening the feedback between the temperature regime and the energy consumption of urbanized territories.

# Abstract (cont.)

Calculation of the influence of energy consumption in urban areas on mesoscale atmospheric processes was carried out from the COSMO-CLM model with the TERRA_URB scheme.

It is shown, that anthropogenic heat fluxes have a noticeable effect on the wind regime of the megalopolis. In the case of the Moscow agglomeration, the average wind speed increases by more than 1 m/s, while the prevailing wind direction changes slightly.

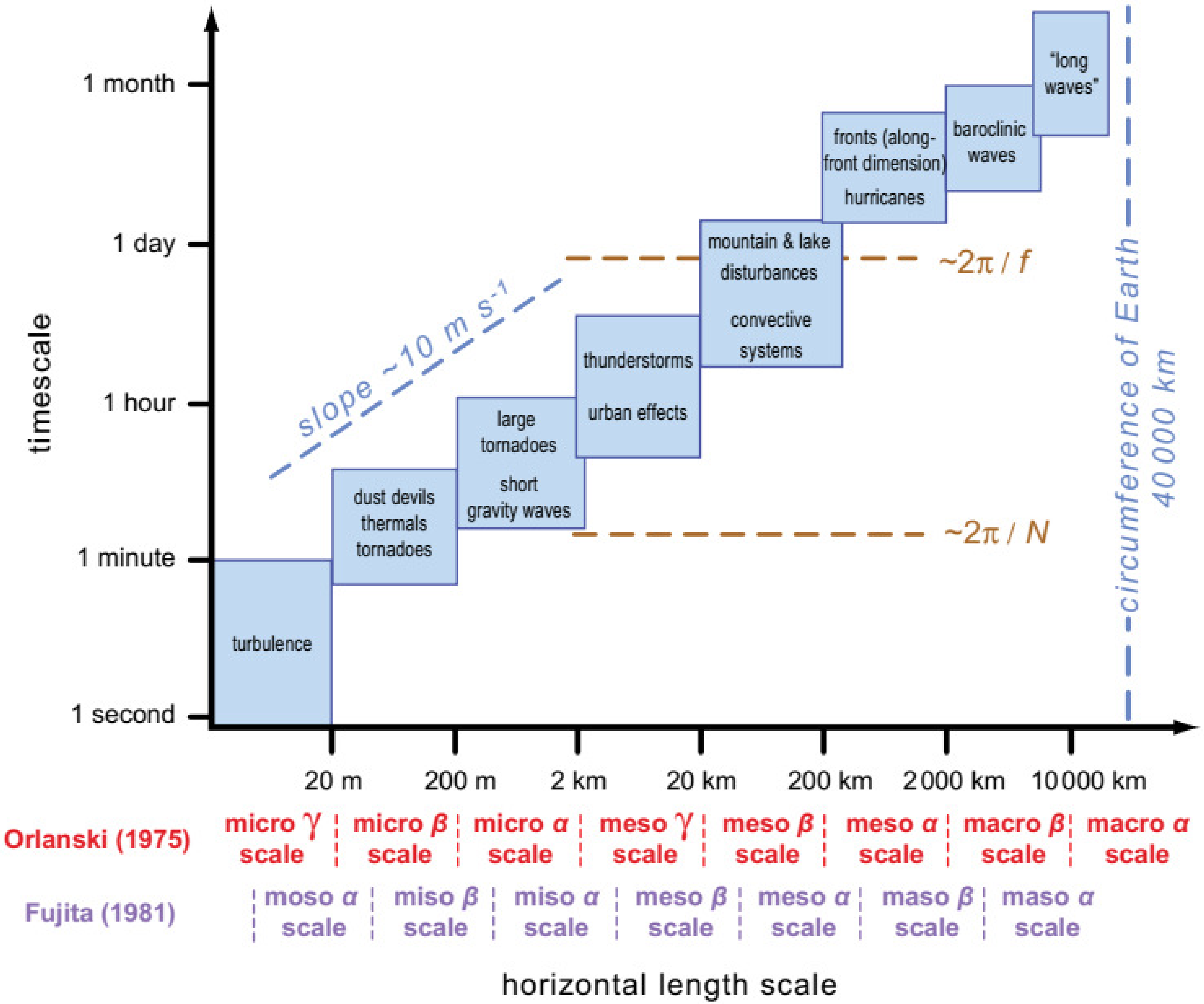
# Climate and Energy of Global City

A global city (world city or alpha city) is an important node (hub) in the global economic system.

European global city elite in 2017 (according ATKearney 2017 report) consists of London, Paris, Berlin, Moscow and Amsterdam.

Urban climate dynamics and anthropogenic impact on the climate have a significant incomplete and fragmentary nature. The dynamics of Moscow's climate is similar to the dynamics of the climate in European cities and it’s investigation has similar problems.

An impact of climate change on the urban energy consumption of the city economy and carbon footprint even less studied than urban climate changes itself.


1 month
1 day
1 hour
1 minute
1 second
timescale
turbulence
dust devils
thermals
tornadoes
large
tornadoes
short
gravity waves
thunderstorms
urban effects
mountain & lake
disturbances
convective
systems
fronts (along-
front dimension)
hurricanes
baroclinic
waves
"long
waves"
slope ~10 m s$^{-1}$
~2π / f
~2π / N
circumference of Earth
40 000 km
20 m
200 m
2 km
20 km
200 km
2 000 km
10 000 km
Orlanski (1975)
micro γ scale
micro β scale
micro α scale
meso γ scale
meso β scale
meso α scale
macro β scale
macro α scale
Fujita (1981)
moso α scale
miso β scale
miso α scale
meso β scale
meso α scale
maso β scale
maso α scale
horizontal length scale

Urban effects are in the middle of the characteristic time and horizontal length scales of atmospheric processes.

The main factor of urban influencing on mesoscale atmospheric and climatic processes are anthropogenic heat fluxes (AHF) caused by all types of sources of thermal energy in urbanized areas - from industry to residents' metabolism.

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# The main methods of AHF estimation:

1. direct (in-situ) measurements of the heat fluxes at the level of roofs;

2. inventory and summing of all consumers of the heat and electric energy in the city with account for the population size and means of transport, length of roads, and engineering communications;

3. remote satellite measurements of the heat radiation fluxes and separation of the anthropogenic fluxes based on the local meteorological data.

The most popular method for AHF estimating is the inventory of heat sources:

$$Q_a = Q_v + Q_b + Q_m ,$$

were $Q_a$ is total AHF, $Q_v$ – heat generated by vehicles, $Q_b$ - heat from buildings, and $Q_m$ - human metabolism.

The alternative method was proposed by author and his co-authors. It based on the use of the most reliable data on the population and energy consumption of the urban economy:

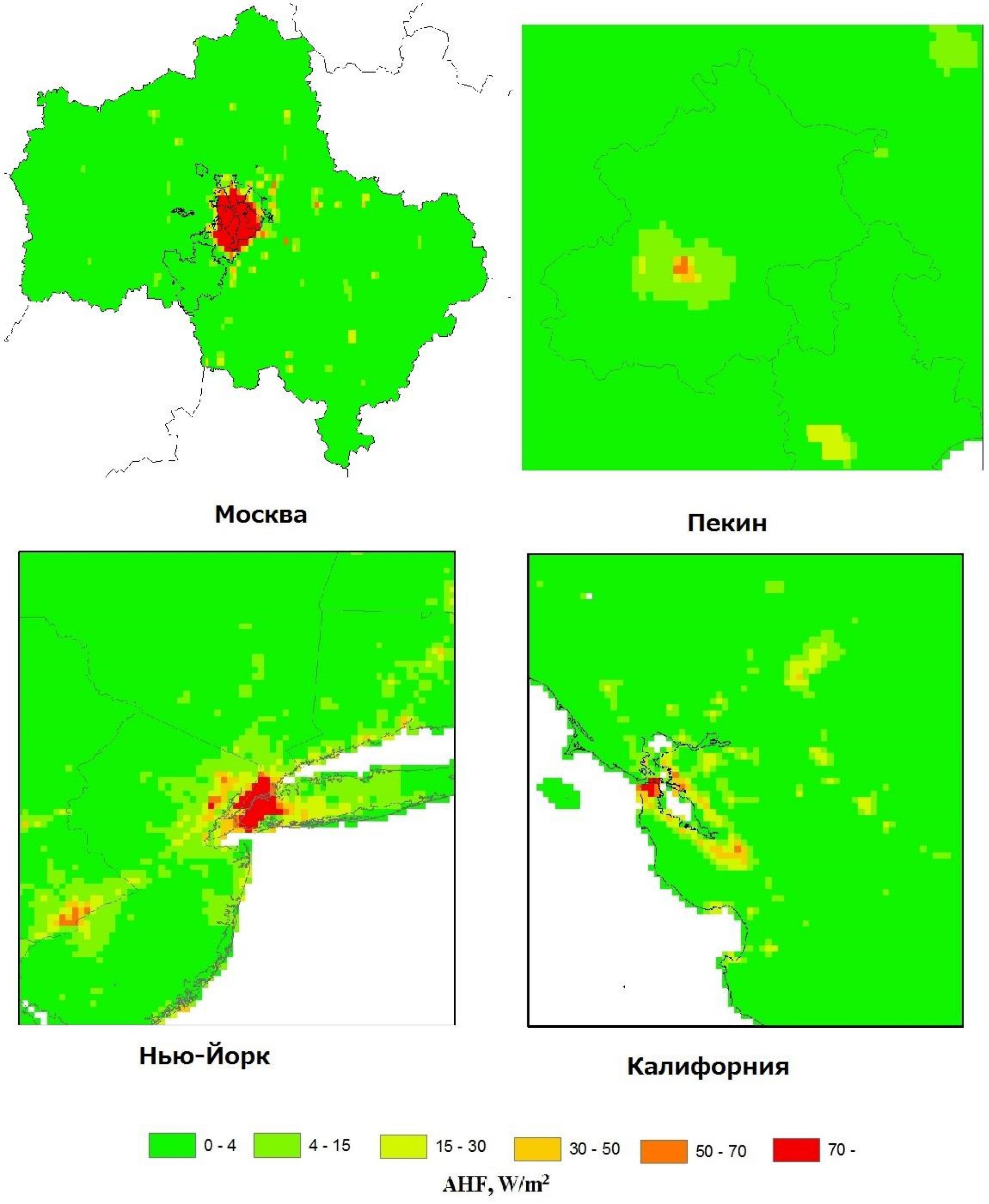
$$Q_a = k \cdot PD \cdot EC$$

where PD is the population density within the urban administrative boundaries, EC is the energy consumption per capita in the country. If $Q_a$ is describing in W/m$^2$, PD in people per sq. km, and EC in kg o.e., the coefficient will be k = 1.325.

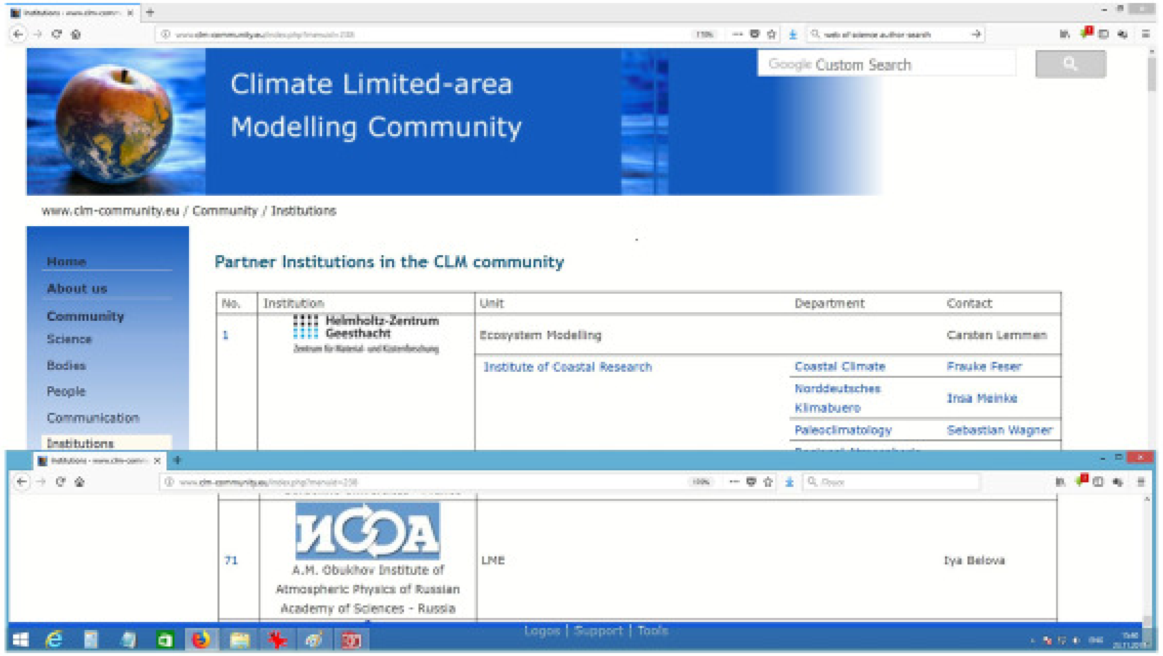

TOTAL HEAT, W/m²
0.0 - 0.5
0.5 - 1.0
1.0 - 2.0
2.0 - 5.0
5.0 - 10.0
10.0 - 25.0
25.0 - 50.0
50.0 - 100.0
100.0 - 192.5

# AHF maps within different largest urban agglomerations around the world

**Moscow,**
**Beijing,**
**New-York,**
**California.**



# COSMO-CLM modeling



Climate Limited-area Modelling Community

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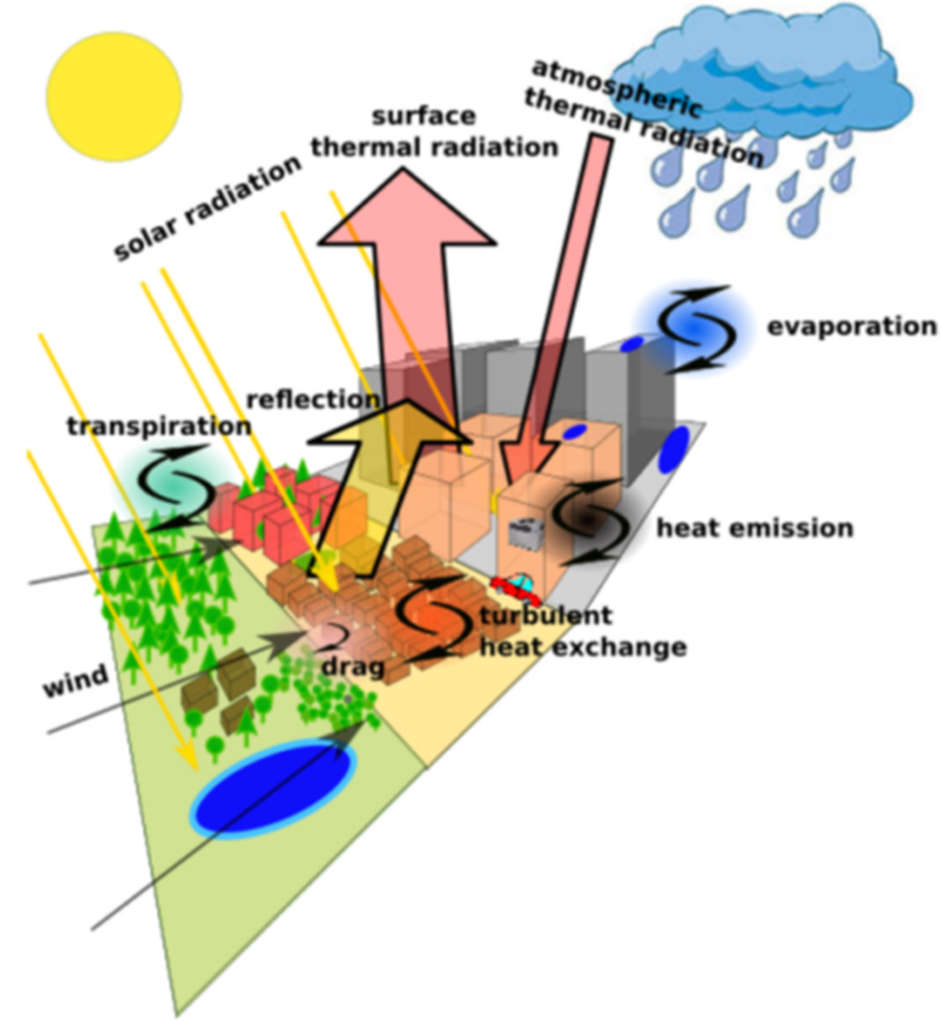
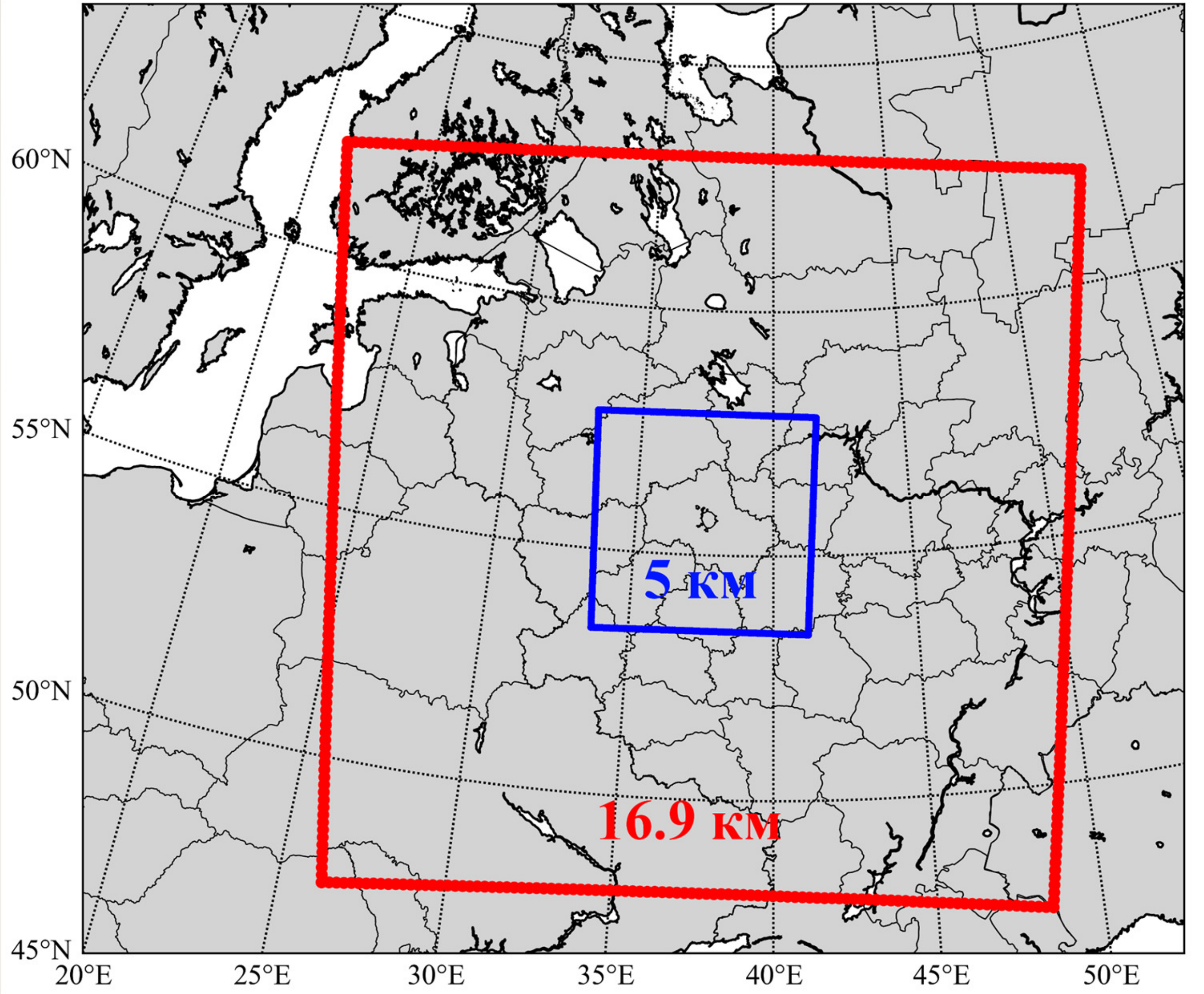
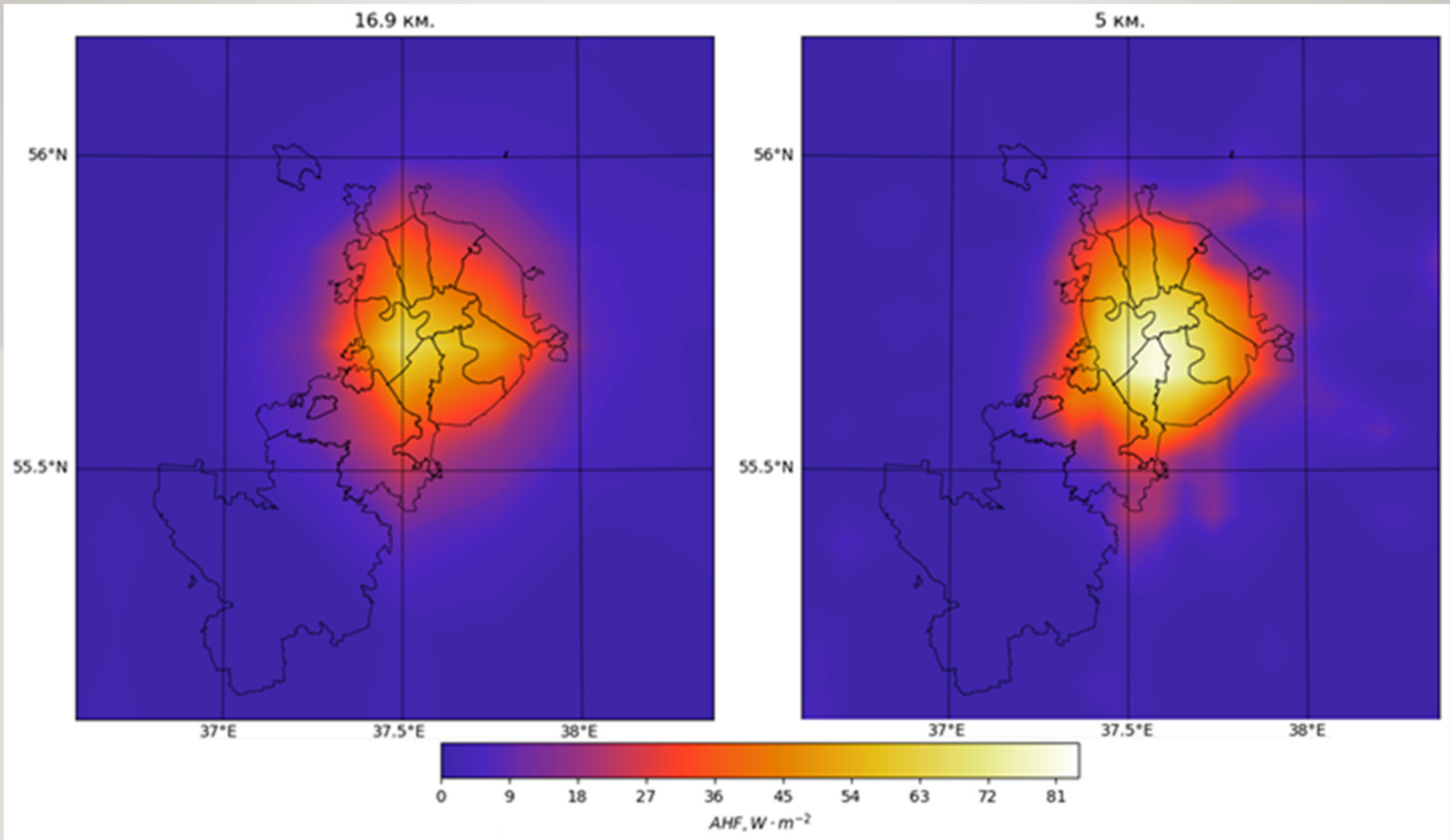
| | | Institute of Coastal Research | Coastal Climate | Frauke Feser |
| | | | Norddeutsches Klimabuero | Insa Meinke |
| | | | Paleoclimatology | Sebastian Wagner |
| 71 | ИФА<br>A.M. Obukhov Institute of Atmospheric Physics of Russian Academy of Sciences - Russia | LME | | Iya Belova |

# TERRA_URB

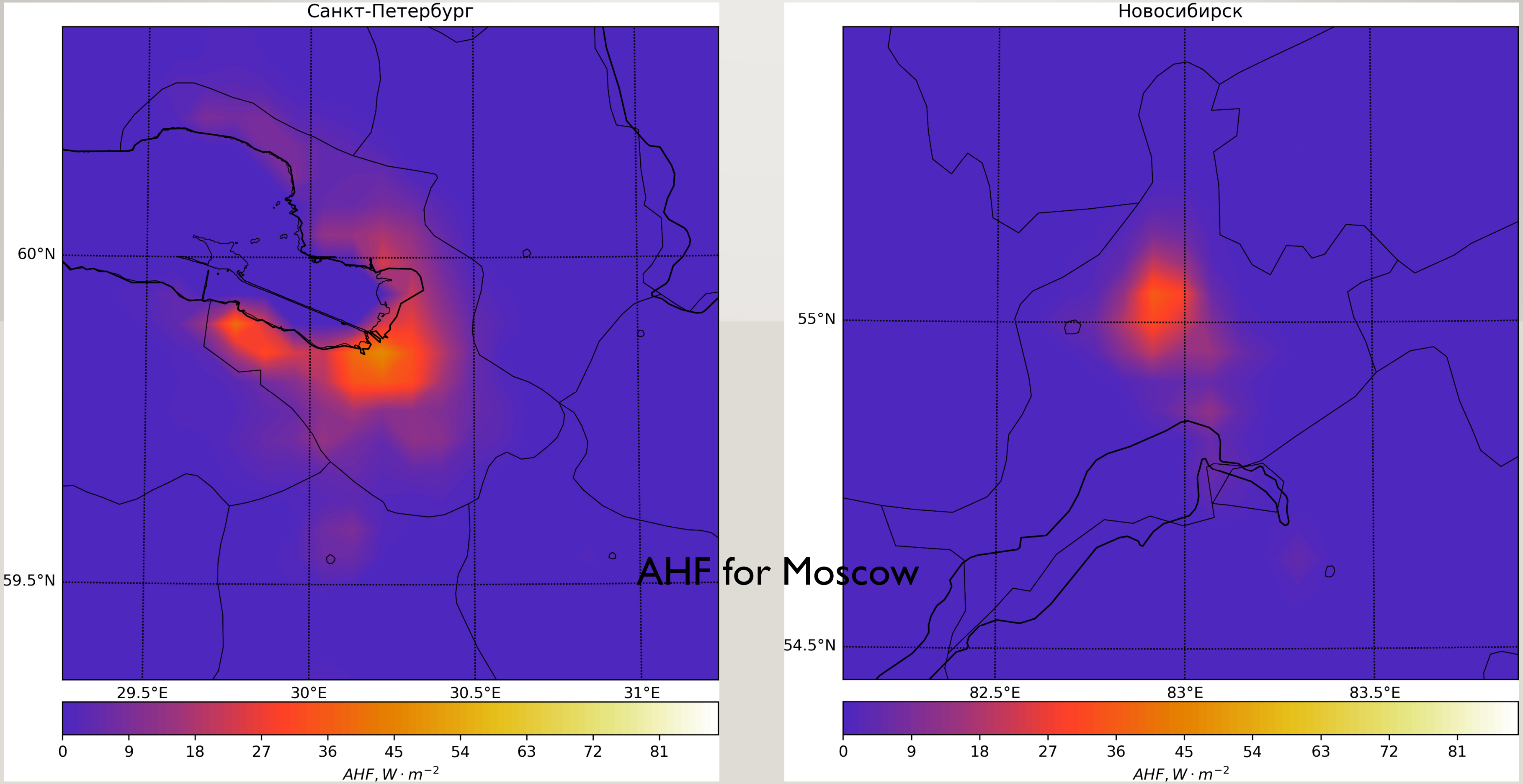

atmospheric
thermal radiation
surface
thermal radiation
solar radiation
evaporation
reflection
transpiration
heat emission
turbulent
heat exchange
drag
wind



**COSMO-CLM domens with different cell sizes: 16,9 and 5 km.**

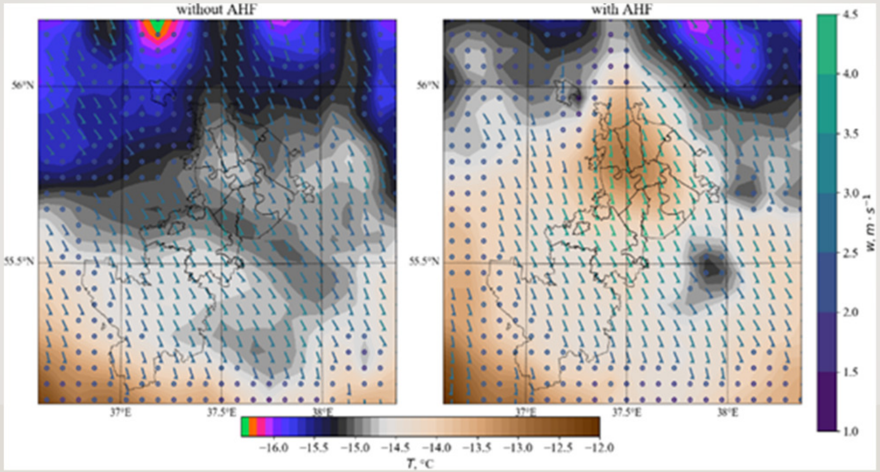


**AHF for Moscow area (COSMO-CLM model with different sell size: left – 16.9x16.9 km, right – 5x5 km)**

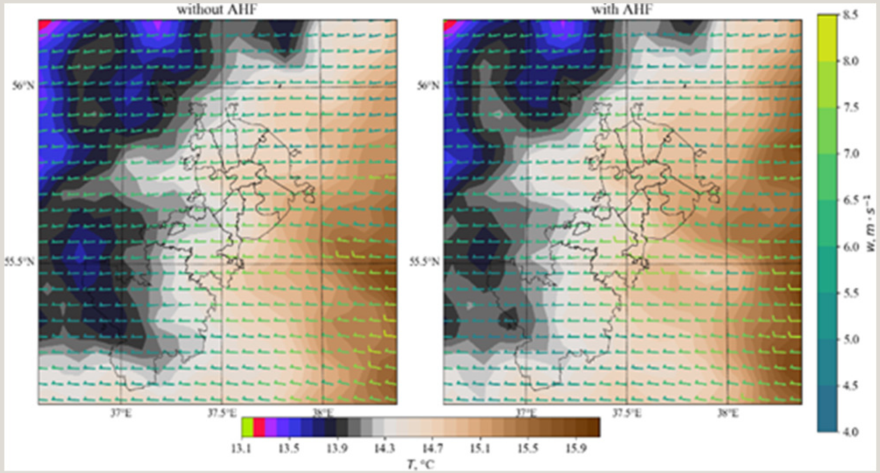


AHF for Moscow

# AHF for Saint-Petersburg (left) and Novosibirsk (right) areas



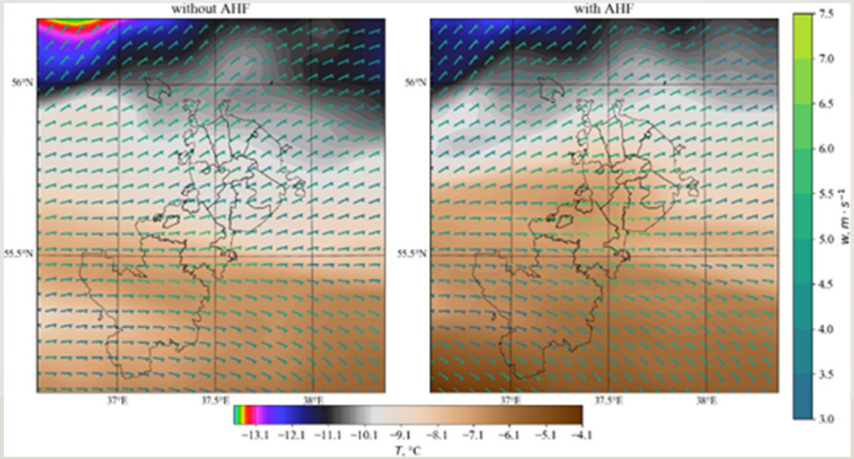
January 5, 2016



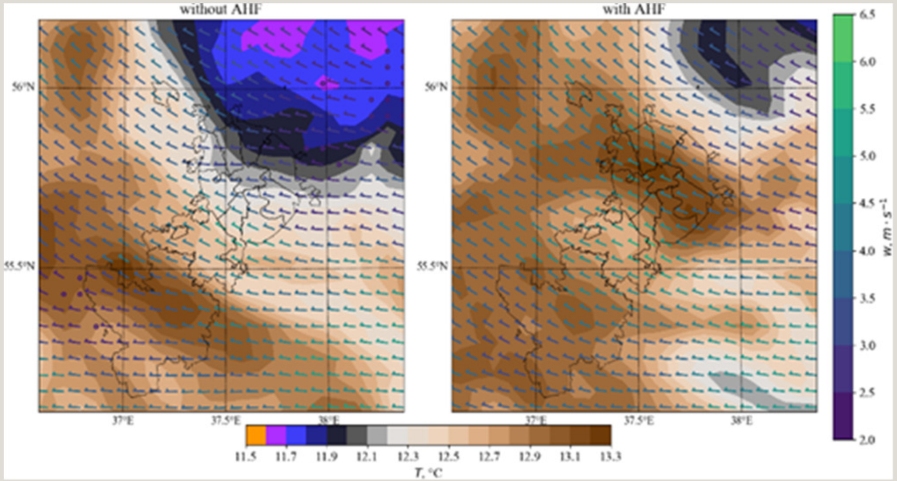
July 5, 2016

## Temperature and wind fields modeling

**left – without AHF, right – with AHF**



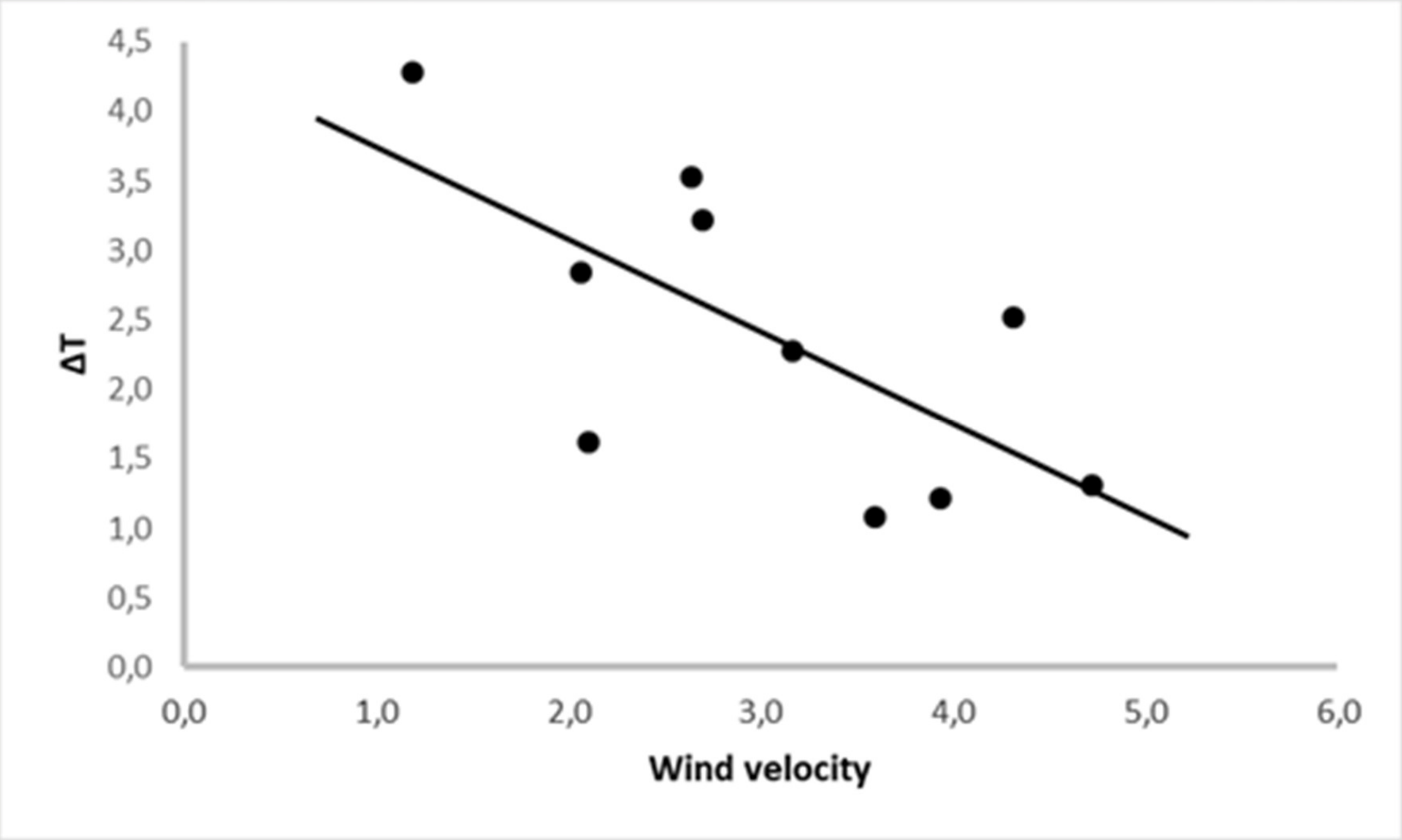
January 5, 2017



July 6, 2017

# Temperature and wind fields modeling left – without AHF, right – with AHF

# AHF influence depends on wind speed



# Mean wind speed depends on AHF
# Moscow, 2017

| | Without AHF | With AHF |
|---|---|---|
| T, C | 1,3 | 3,1 |
| Wind, m/c | 2,9 | 3,9 |

# Heating and Cooling Periods and Degree-Days

The duration of indoor heating periods in various countries and regions of the world is defined in different ways.

In Russia, the heating season generally starts on the date when average daily air temperature stably (for 5 days) falls below the level of +8°C in autumn and ends on the date when it stably (for 5 days) rises above this level in spring.

Due to climate warming several last winters in Moscow region had the 2-3 weeks periods with mean daily air temperature above +8°C and Moscow city authority switched off city district heating system for about a week.

Heating degree day (HDD) is the parameter, which is applied to estimate the energy amount needed to heat indoor living and public spaces.

HDD is calculated as follows:

$$HDD = \sum_{i=1}^{N} (t_c - t_{ai})$$

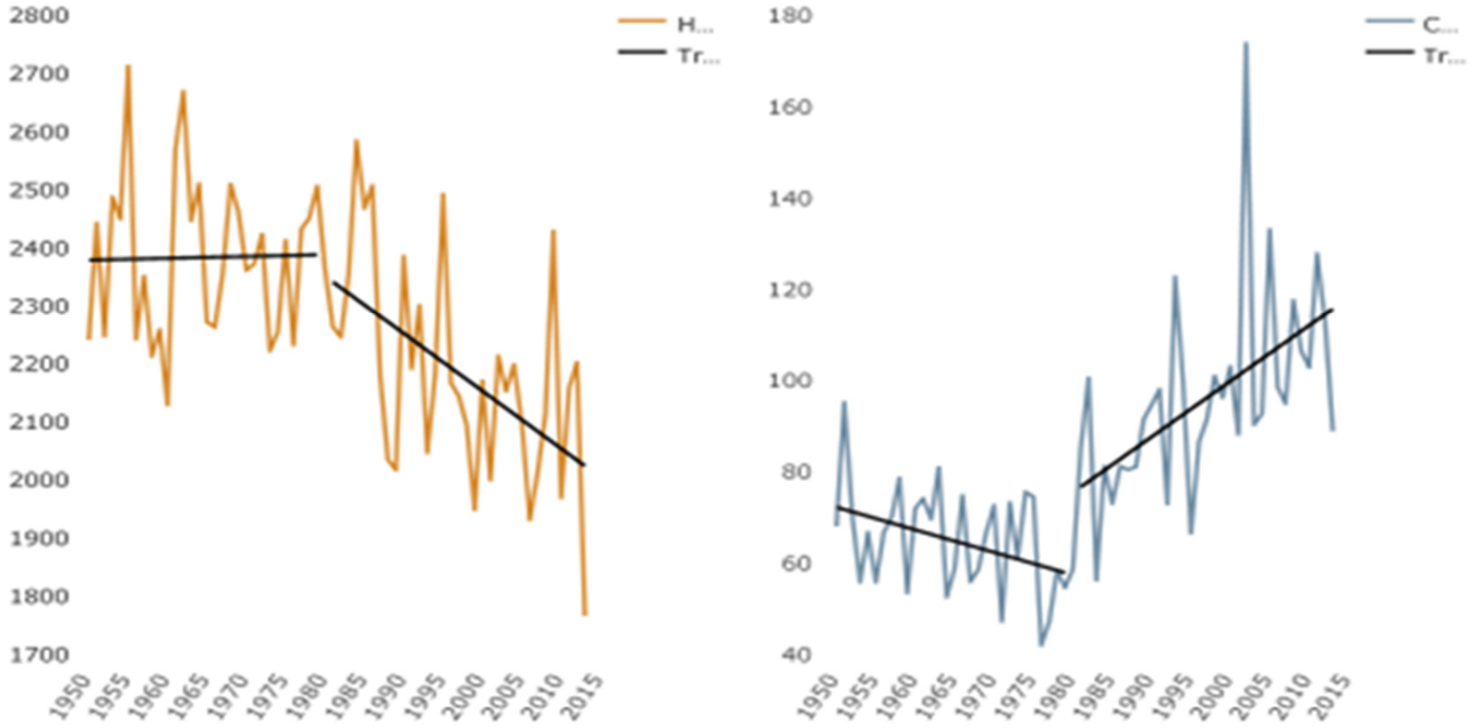
where N is the number of days within heating period, when ta bellow 8 °C.

# HDD online calculator

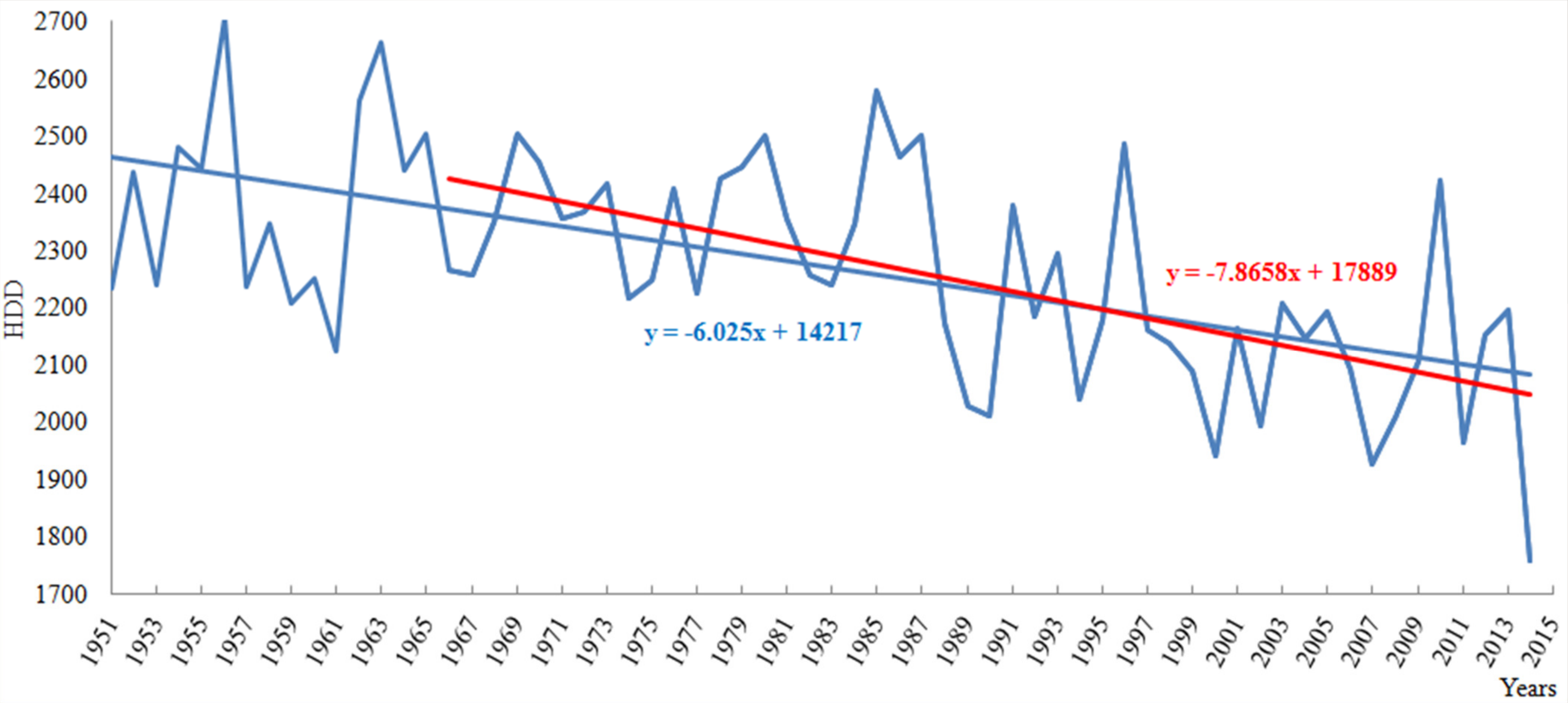
$$HDD\_CDD = \sum_{i=1}^{N} |18 - T_i|$$

| | |
|---|---|
| 21 декабря | -2.0 °C |
| 22 декабря | -4.0 °C |
| 23 декабря | -4.5 °C |
| 24 декабря | -4.5 °C |
| 25 декабря | -3.0 °C |
| 26 декабря | -4.0 °C |
| 27 декабря | -2.5 °C |
| HDD_CDD | 150.5 |

**Moscow, December 2017**



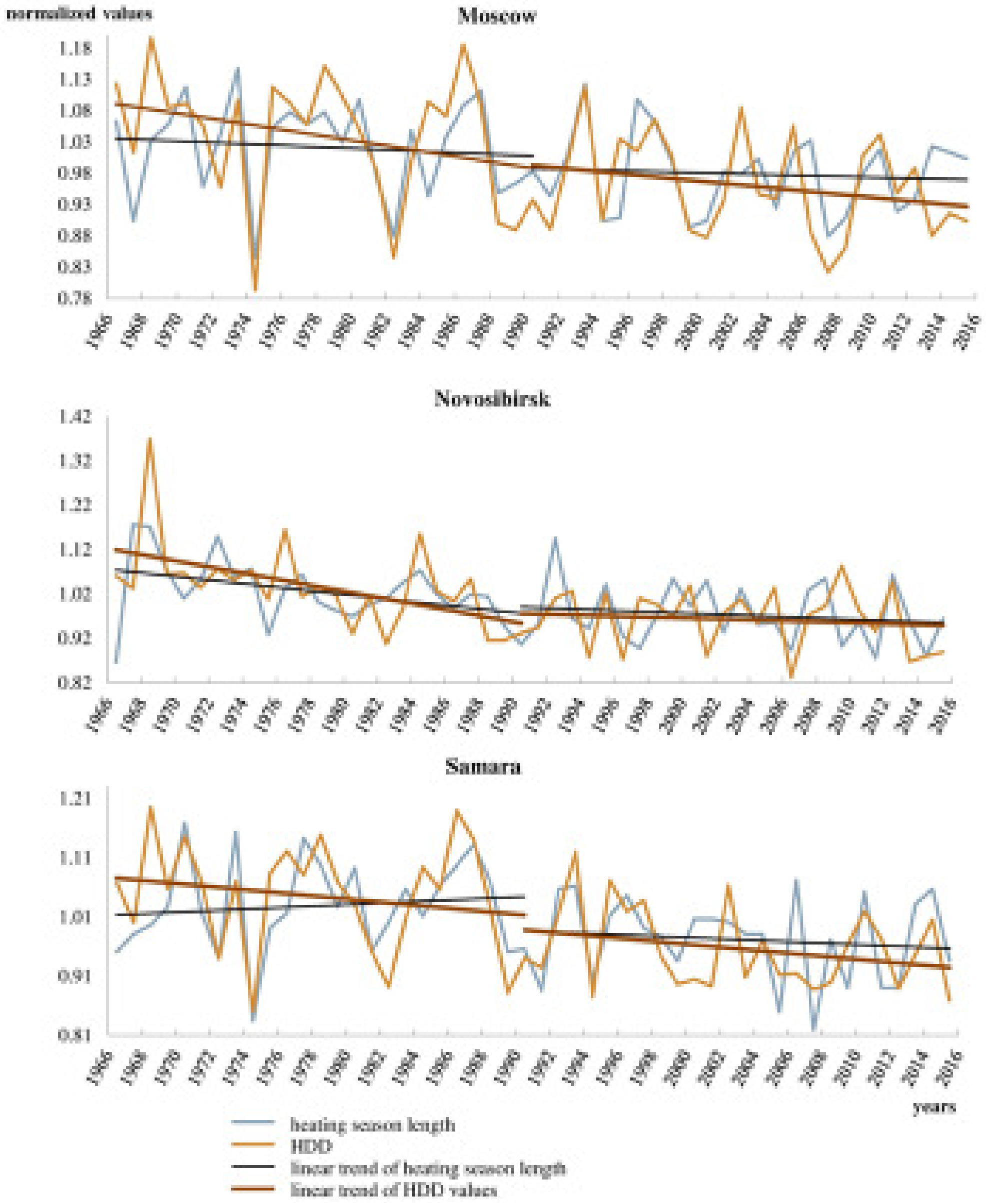
**Heating and Cooling degree days (HDD & CDD) averaged over Europe. EEA. 2016**

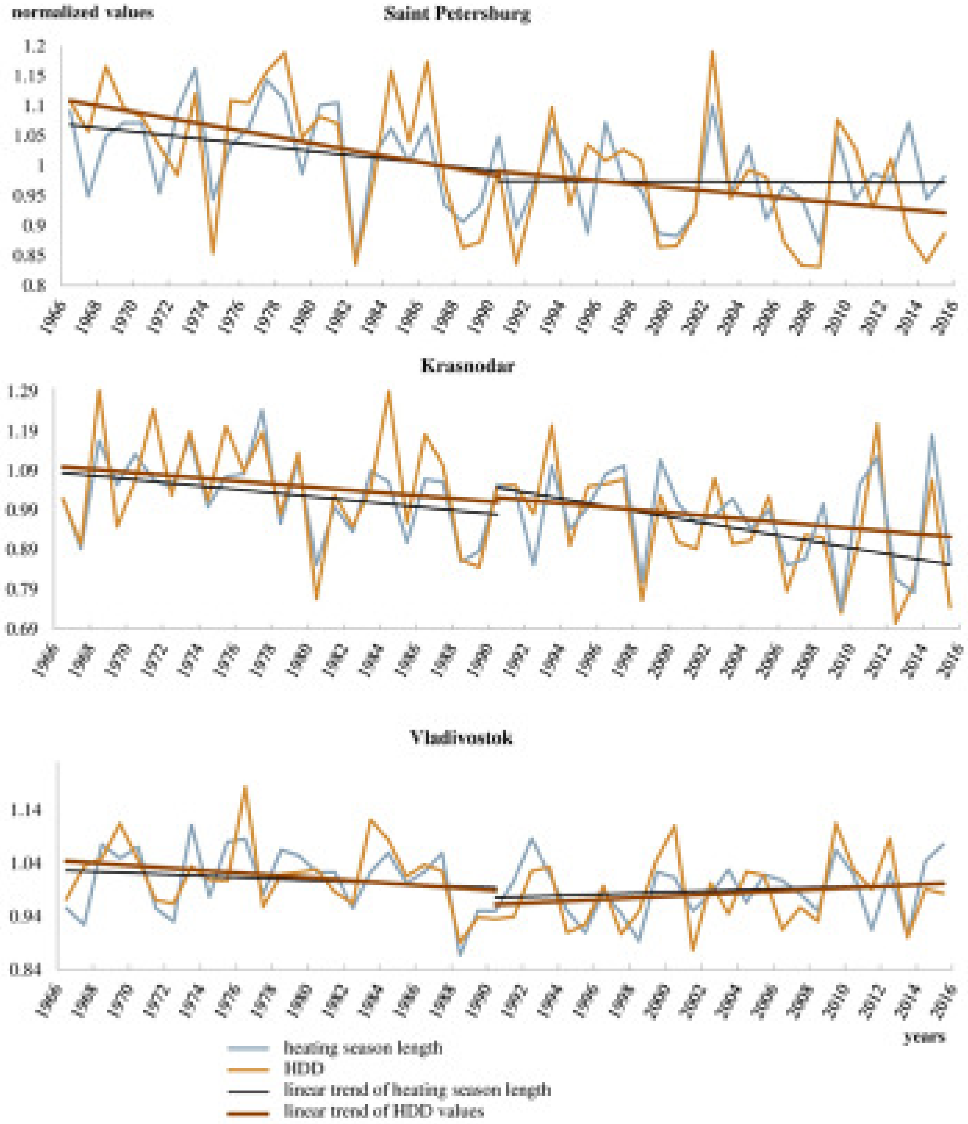


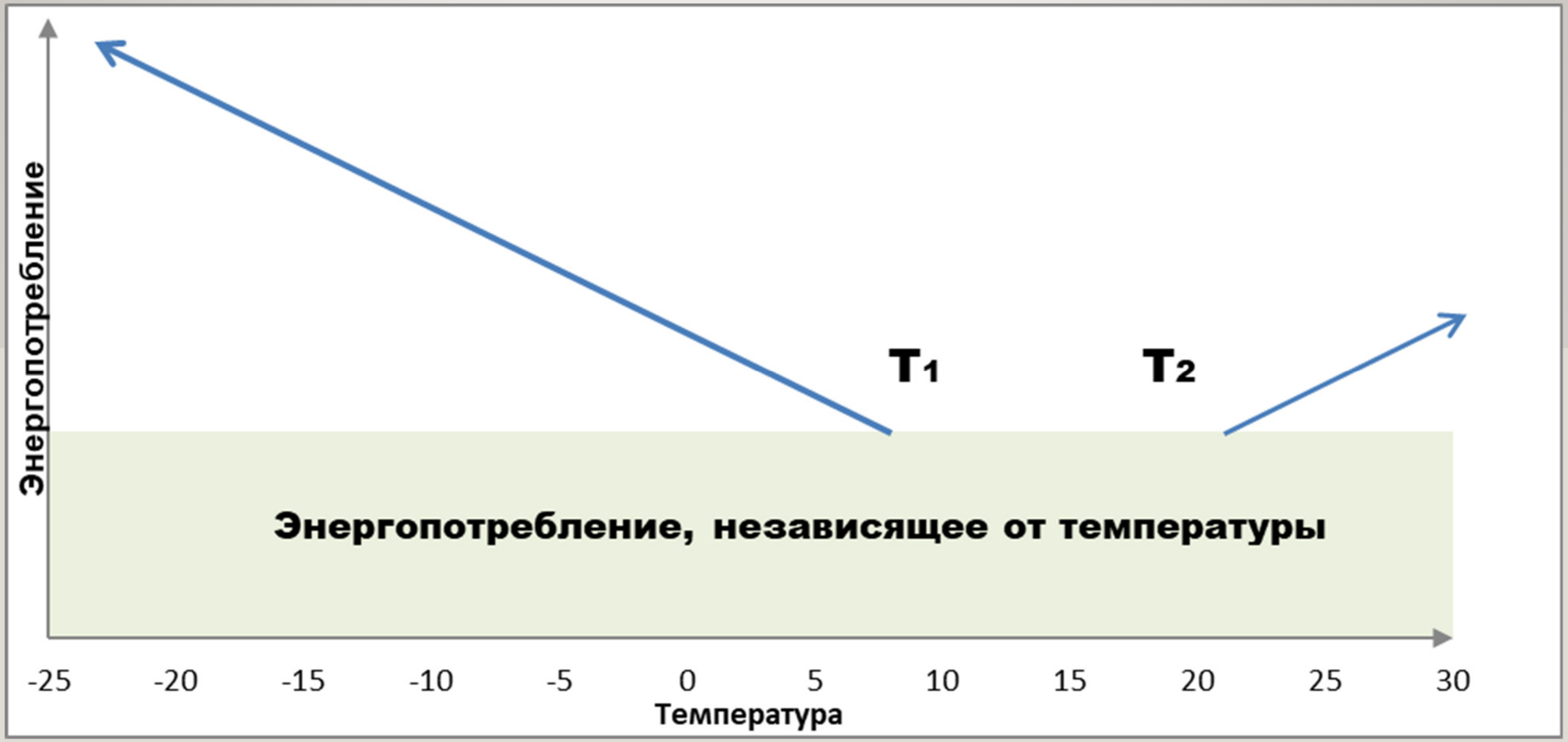
Dynamics of the number of degree-days of the heating season in the EU countries

Selected Russian large cities

| City | Average heating season length (days) | Average HDD |
|---|---|---|
| **Moscow** | 201 | 4129 |
| **Samara** | 198 | 4502 |
| **Novosibirsk** | 223 | 5768 |
| **Saint Petersburg** | 210 | 4088 |
| **Krasnodar** | 143 | 2270 |
| **Vladivostok** | 193 | 4808 |


normalized values
Moscow
1.18
1.13
1.08
1.03
0.98
0.93
0.88
0.83
0.78
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Novosibirsk
1.42
1.32
1.22
1.12
1.02
0.92
0.82
Samara
1.21
1.11
1.01
0.91
0.81
years
heating season length
HDD
linear trend of heating season length
linear trend of HDD values


normalized values
Saint Petersburg
1.2
1.15
1.1
1.05
1
0.95
0.9
0.85
0.8
1966
1968
1970
1972
1974
1976
1978
1980
1982
1984
1986
1988
1990
1992
1994
1996
1998
2000
2002
2004
2006
2008
2010
2012
2014
2016
Krasnodar
1.29
1.19
1.09
0.99
0.89
0.79
0.69
Vladivostok
1.14
1.04
0.94
0.84
years
heating season length
HDD
linear trend of heating season length
linear trend of HDD values



The scheme of the effect of air temperature on space heating and air conditioning. The characteristic temperature range without heating and air conditioning is from 8 to 22 ° C.

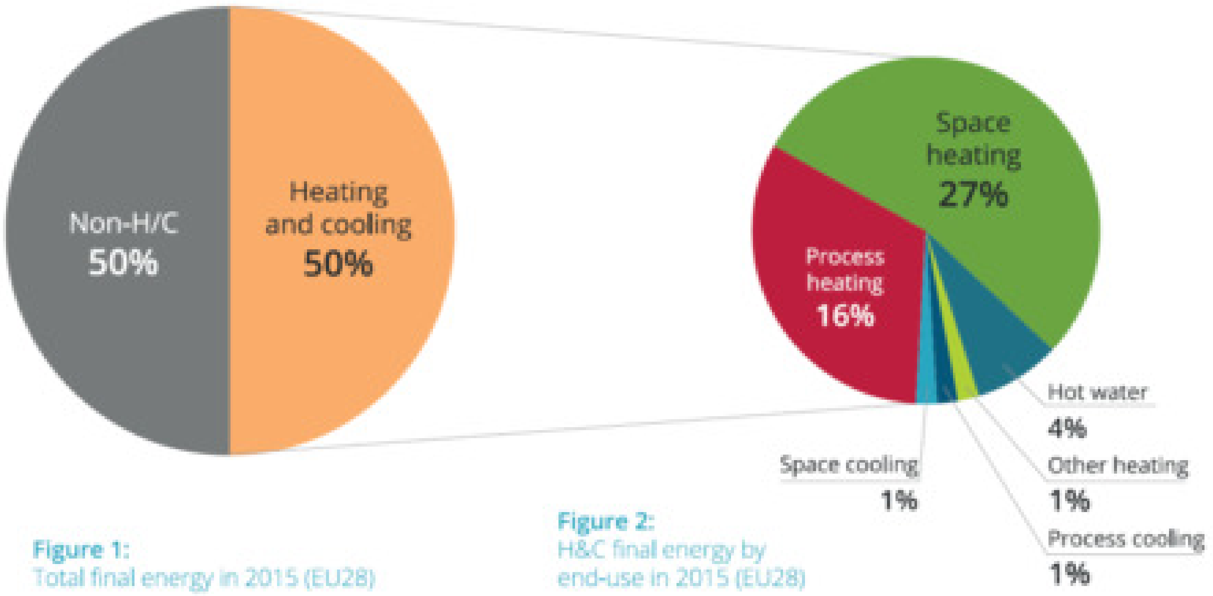
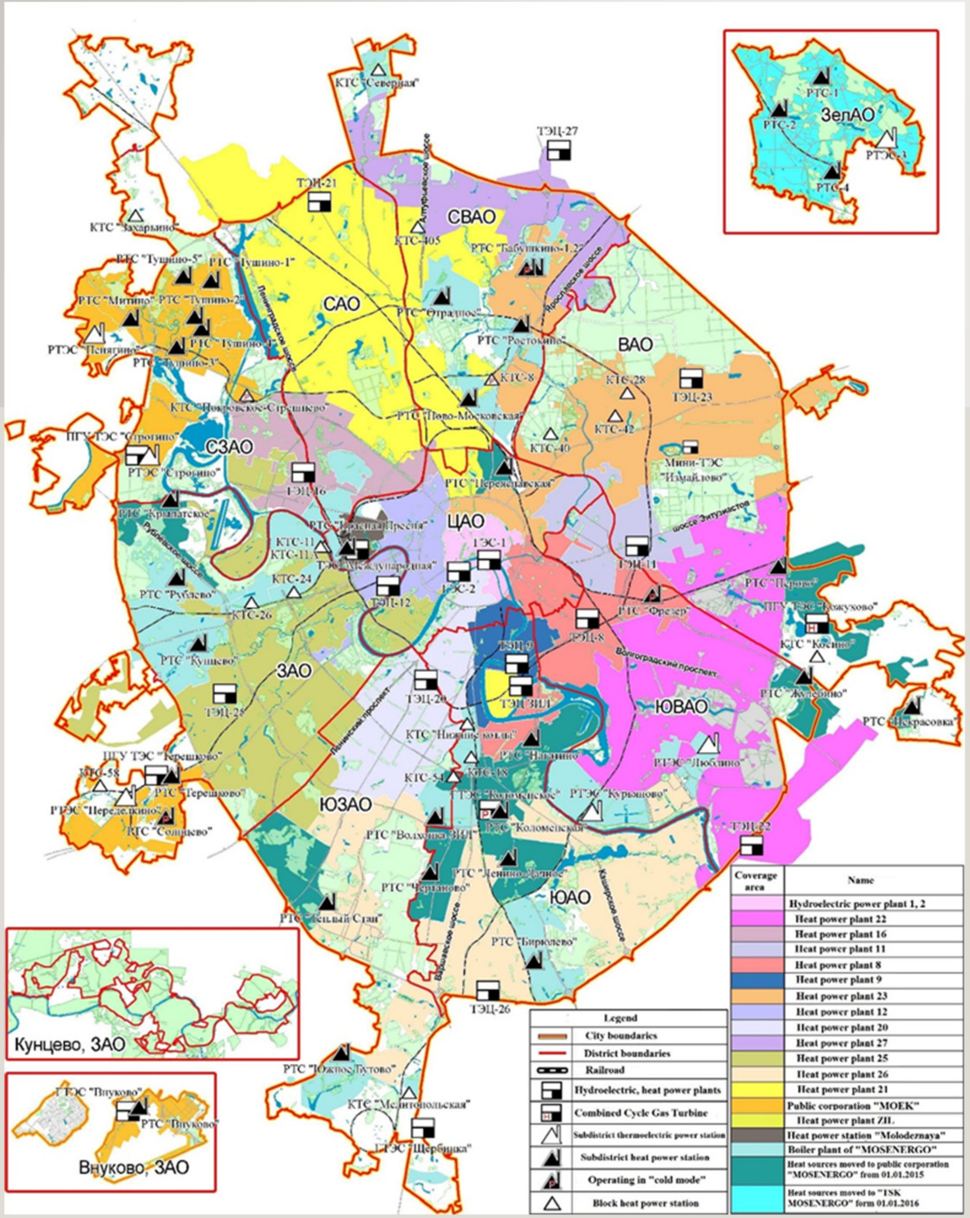


Figure 1:
Total final energy in 2015 (EU28)

Figure 2:
H&C final energy by end-use in 2015 (EU28)

# Heat Roadmap Europe, June 2017 Heating and Cooling: 50 % of EU Energy Demand

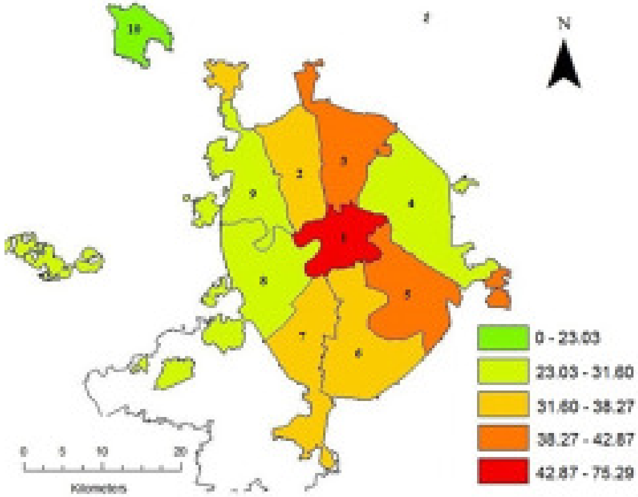


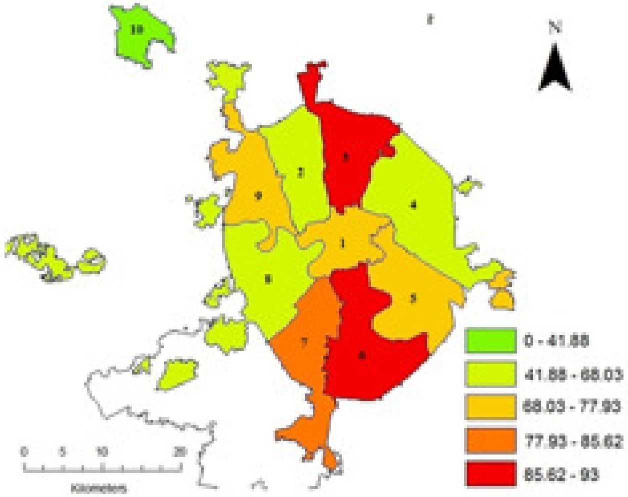
# Moscow district heating sistem

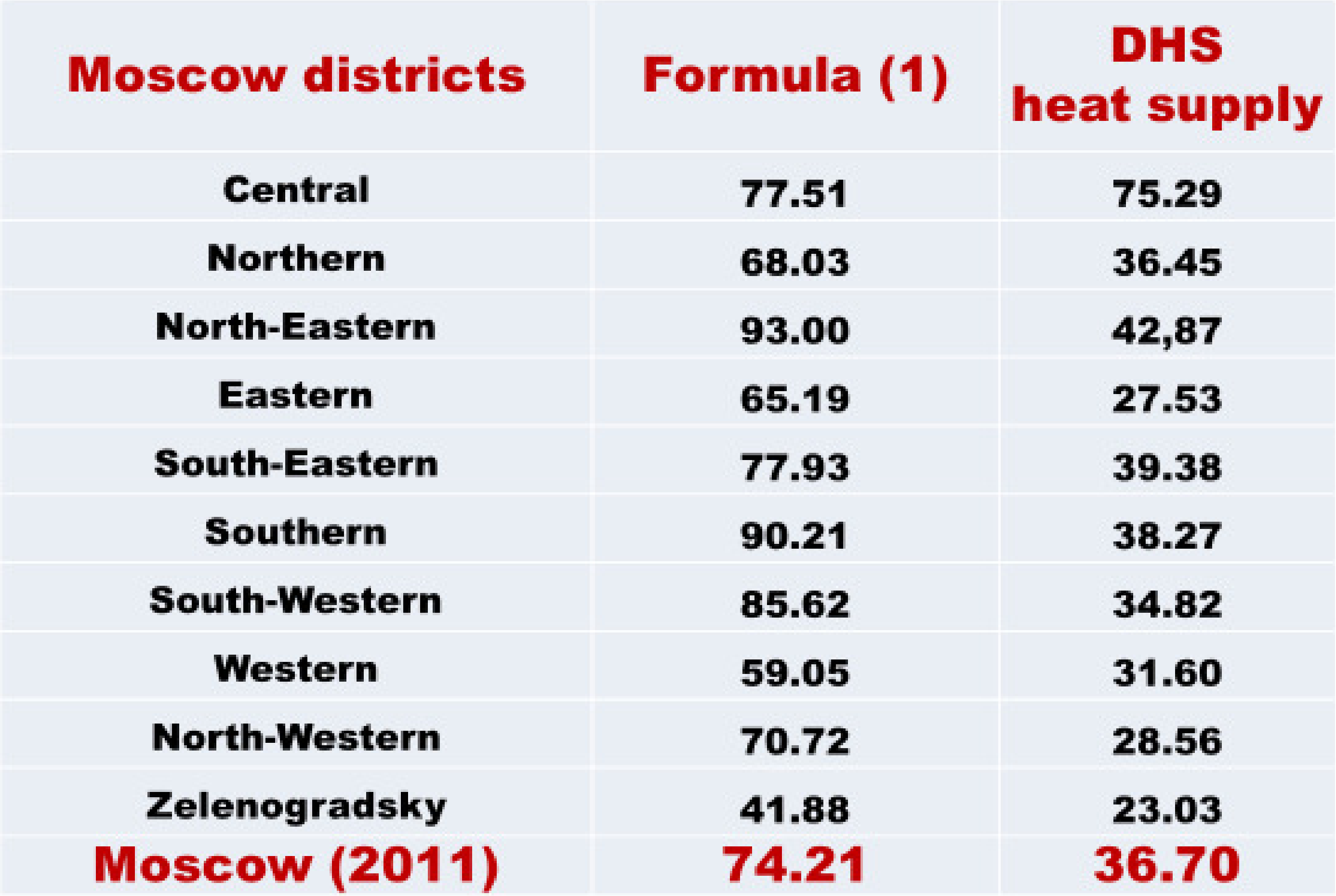
# Anthropogenic heat fluxes

$$Q_a = k \cdot PD \cdot EC$$

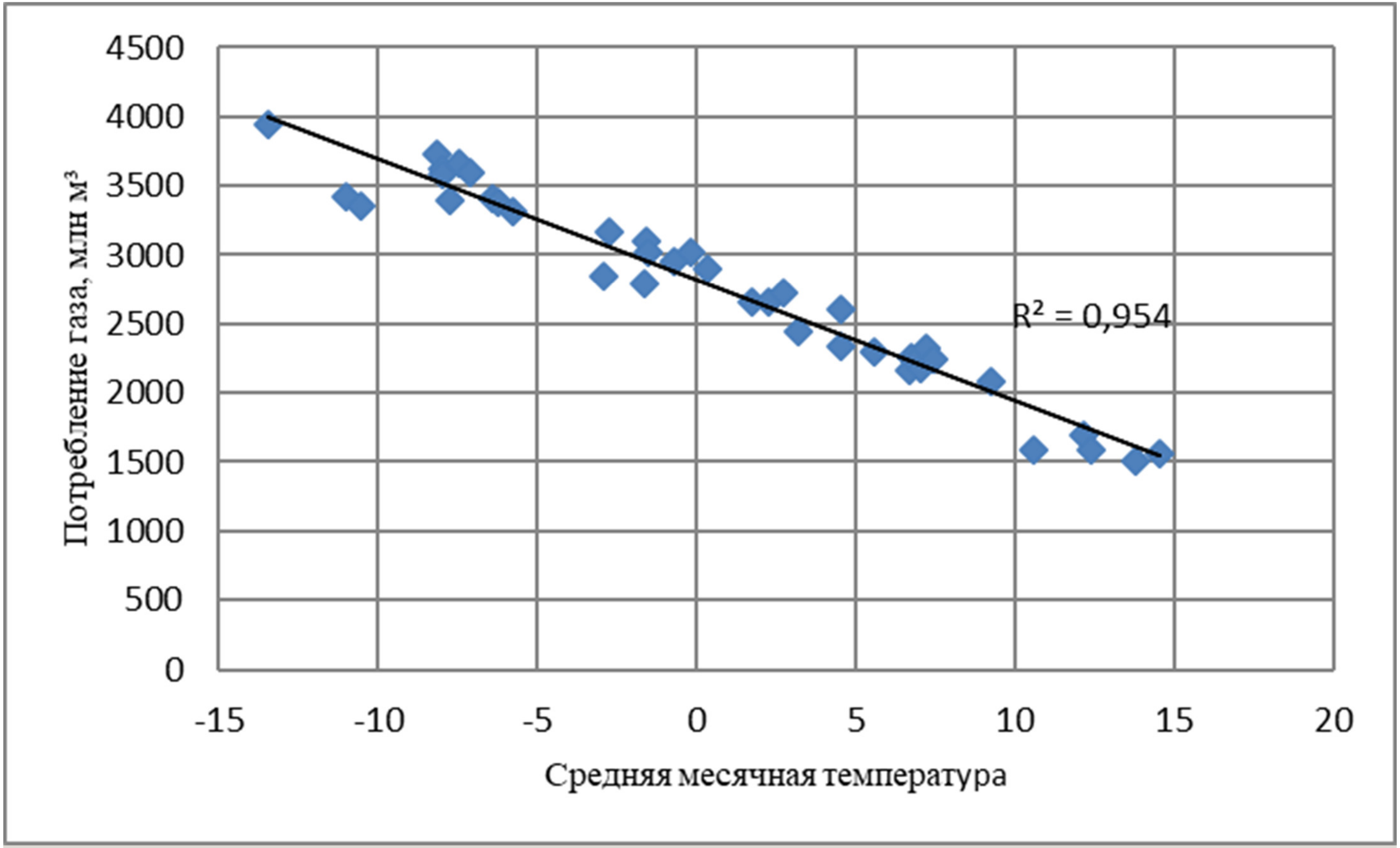
$$AHF = G \cdot \frac{C_{GW}}{S}$$

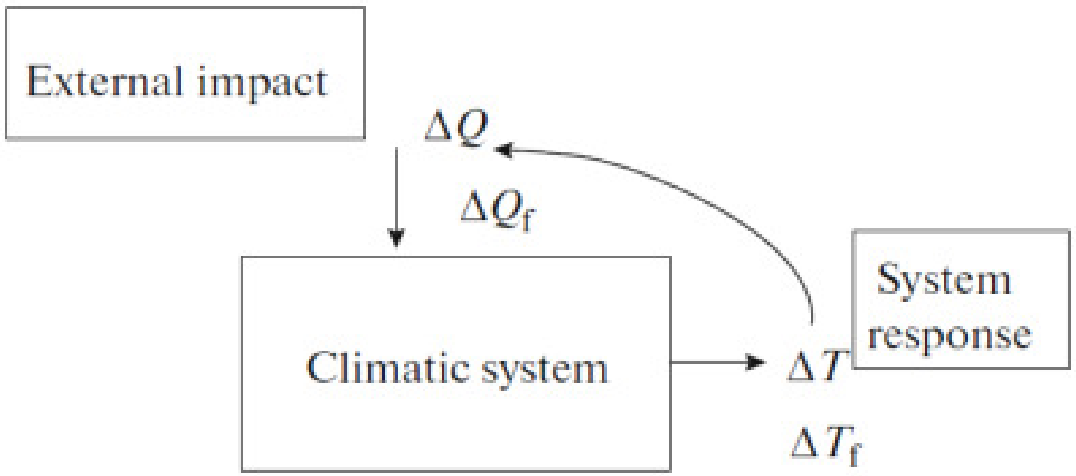






| Moscow districts | Formula (1) | DHS heat supply |
|---|---|---|
| Central | 77.51 | 75.29 |
| Northern | 68.03 | 36.45 |
| North-Eastern | 93.00 | 42,87 |
| Eastern | 65.19 | 27.53 |
| South-Eastern | 77.93 | 39.38 |
| Southern | 90.21 | 38.27 |
| South-Western | 85.62 | 34.82 |
| Western | 59.05 | 31.60 |
| North-Western | 70.72 | 28.56 |
| Zelenogradsky | 41.88 | 23.03 |
| **Moscow (2011)** | **74.21** | **36.70** |


Потребление газа, млн м³
4500
4000
3500
3000
2500
2000
1500
1000
500
0
-15
-10
-5
0
5
10
15
20
Средняя месячная температура
R² = 0,954



$$\Delta Q_f = \Delta Q + \Delta Q_{fb}$$
$$\Delta T_f = \Delta T + \Delta T_{fb}$$

**Fig. 1.** General diagram of feedback action. $\Delta Q$ is the external impact, for example, radiative forcing due to doubling of the $CO_2$ content, $\Delta T$ is the direct change in the surface temperature, $\Delta Q_{fb}$ is the change in external impact due to feedback, $\Delta T_{fb}$ is the change in the surface temperature due to feedback, and $\Delta Q_f$ and $\Delta T_f$ are the final changes in forcing and system response.

# Acknowledgments

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