*TEKA Kom. Mot. Energ. Roln. – OL PAN, 2008, 8a, 180–187*

# DETERMINATION OF HEAT DEMAND IN RURAL COMMUNES

Małgorzata Trojanowska, Tomasz Szul

Department of Agricultural Energetics, Agricultural University of Cracow
Balicka Str. 116B, 30-149 Kraków, Poland, 3,
e-mail: trojanowska@ar.krakow.pl; tszul@ar.krakow.pl

**Summary.** The paper presents a model, which supports energy management and planning in rural communes related to heat demand. The model allows to determine final energy consumption for heating and preparing of hot usable water and meals in all buildings/facilities located in a commune, with error not exceeding ±5%. Presented model was used to determine heat demand for rural consumers located in South-Eastern Poland.

**Key words:** energy consumption planning, heat demand, rural commune.

## INTRODUCTION

The Act on *Local Government* [Dz.U. 1990 nr 16 poz. 95] defines own objectives for communes, involving the issues of heat supply, electric energy and gas fuels. On the other hand, the *Energy Law* [Dz.U. z 1997 r. nr 54] assigns to communes the role and obligations of central self-government planner and organizer in this regard. The act obliges local governments to drawing up draft principles for the plans as well as the plans for local energy supply, including energy supply organization.

Local energy planning is a relatively new term. Commune governments do not have sufficient experience in executing assignments of this type, and at the same time there is a shortage of studies supporting energy planning at local stage [Trojanowska, Szul 2003].

The assessment of current energy demand makes the starting point in planning. Determination of thermal needs is an especially difficult task, especially in rural areas. Accurate assessment of heat demand is important in energy consumption planning, considering the fact that in Poland approximately 40% of all primary energy carriers are consumed for room heating purposes [Mróz 1999; Robakiewicz 1999].

The purpose of the work was to present models supporting energy management and planning in rural communes related to heat demand, and to use it in order to determine heat demand for rural consumers located in South-Eastern Poland.

## MATERIAL AND METHOD

For the purpose of the work, models describing final energy consumption in all rural buildings for their heating as well as for preparation of hot usable water and meals were developed. Quantities significantly correlated with energy consumption for the above-mentioned purposes, available in statistical statements of communes, were selected as input variables for the models. These quantities included: population of inhabitants, number of farms and their structure regarding number of persons living in a farm, number of buildings and their construction year, cubic capacity of residential buildings, cubic capacity of public buildings/facilities, area and type of crops grown under covers.

Mixed approach was applied when developing those models, involving simultaneous application of both end-use [Malko 1995] and econometric methodology [Gajda 2004]. Studies were performed to verify the models in 400 randomly selected farms and in infrastructural facilities in three rural communes in Southern Poland.

## RESULTS

**The form of the model**

The model describes consumption of final energy for heating and preparing of hot usable water and meals in all buildings/facilities located in a commune, which are grouped in three sectors:

– housing construction,
– public buildings construction, divided into social and economic infrastructure facilities,
– agricultural-production, including grown under covers (applicable to heated facilities).

The following formula shows total demand for thermal energy in a rural commune:

$$B = B_{OGD} + B_{OGU} + B_{OGR} + B_{CWU} + B_{POS}, \tag{1}$$

$$B_{OGD} = \sum_{i=1}^{m}\sum_{j=1}^{m} L_{Bm_{ij}} \cdot \overline{B}_{ogm_{ij}}, \tag{2}$$

$$B_{OGU} = \sum_{j=1}^{m} L_{Bu_j} \cdot B_{ogu_j}, \tag{3}$$

$$B_{OGR} = \sum_{c=1}^{m}\sum_{g=1}^{m} L_{Us_{cg}} \cdot B_{Rs_{cg}} + \sum_{c=1}^{m}\sum_{g=1}^{m} L_{Uf_{cg}} \cdot B_{Rf_{cg}}, \tag{4}$$

$$B_{CWU} = \sum_{j=1}^{m} B_{cwu_j}, \tag{5}$$

$$B_{POS} = \sum_{k=1}^{m}\sum_{j=1}^{m} L_{GD\,kj} \cdot B_{pos_{kj}}, \tag{6}$$

where:

$B$ – total thermal energy demand in a commune [tpu],
$B_{OGD}$ – energy demand for heating of residential buildings [tpu],
$B_{OGU}$ – energy demand for heating of public buildings/facilities [tpu],
$B_{OGR}$ – energy demand for heating of crops grown under covers [tpu],

$B_{CWU}$ – energy demand for preparation of hot usable water [tpu],

$B_{POS}$ – energy demand for preparation of meals [tpu],

$L_{Bm_{ij}}$ – number of residential buildings from the $i^{-th}$ age bracket, heated using the $j^{-th}$ energy carrier [pcs.],

$\overline{B}_{ogm_{ij}}$ – energy demand for heating of a statistical residential building from the $i^{-th}$ age bracket using the $j^{-th}$ energy carrier [tpu],

$L_{Bu_j}$ – number of public buildings/facilities heated using the $j^{-th}$ energy carrier [pcs.],

$B_{ogu_j}$ – energy demand for heating of a public building/facility using the $j^{-th}$ energy carrier [tpu],

$L_{Us_{cg}}$ – number of greenhouse buildings characterised by the $g^{-th}$ thermal losses, in which farmers grow plants that belong to the $c^{-th}$ group of thermal requirements [pcs.],

$B_{Rs_{cg}}$ – energy demand for heating of a greenhouse characterised by the $g^{-th}$ thermal losses, in which farmers grow plants that belong to the $c^{-th}$ group of thermal requirements [tpu],

$L_{Uf_{cg}}$ – number of heated foil tunnels characterised by the $g^{-th}$ thermal losses, in which farmers grow plants that belong to the $c^{-th}$ group of thermal requirements [pcs.],

$B_{Rf_{cg}}$ – energy demand for heating of a foil tunnel characterised by the $g^{-th}$ thermal losses, in which farmers grow plants that belong to the $c^{-th}$ group of thermal requirements [tpu],

$B_{cwu_j}$ – energy demand for preparing of hot usable water using the $j^{-th}$ energy carrier [tpu],

$L_{GDkj}$ – number of households with $k^{-th}$ number of people preparing meals using the $j^{-th}$ energy carrier [*pcs.*],

$B_{pos_{kj}}$ – energy demand for preparing of meals by a family consisting of $k$ persons using the $j^{-th}$ energy carrier [tpu].

Models of energy demand for heating of individual buildings, and preparation of hot usable water and meals are listed in Tab. 1 and 3.

Table 1. Models of annual energy demand for heating of buildings in the tpu

| Specification | Empirical formula |
|---|---|
| Energy demand for heating of a residential building | $B_{ogm} = c_1 \cdot V^{\frac{5}{6}} \cdot w \cdot \eta_k^{-1}$ |
| Energy demand for heating of a public building/facility | $B_{ogu} = c_2 \cdot V \cdot \eta_k^{-1}$ |
| Energy demand for greenhouse heating | $B_{R_s} = c_3 \cdot q_s \cdot A_G \cdot \eta_k^{-1}$ |
| Energy demand for foil tunnel heating | $B_{R_f} = c_4 \cdot q_f \cdot A_G \cdot \eta_k^{-1}$ |

where:

V – building cubage [$m^3$],

w – corrective factor [Szul 2005; Trojanowska, Szul 2006],

$\eta_k$ – boiler efficiency,

$q_s$ – the index of unit heat demand for greenhouse heating [$W \cdot m^{-2}$] [von Zabeltitz 1991],

$q_f$ – the index of unit heat demand for foil tunnel heating [$W \cdot m^{-2}$] [Kurpaska 2003; Kurpaska, Latała 2004 ],

$A_G$ – cropland area [$m^2$],

$c_1$, $c_2$, $c_3$, $c_4$, – constants (tab.2).

Table 2. Values of constants $c_1 - c_4$

| $c_1$ | $c_2$ | $c_3$ | $c_4$ |
|---|---|---|---|
| 0.014 for residential buildings heated with gas or using heat pumps, 0.0175 for residential buildings heated with solid fuels | 0.0083 | 0.00037 | 0.00028 |

The following values were used in further computations:
$\eta_k$=0.7 for boilers fired with solid fuel, currently in use,
$\eta_k$=0.8 for modern boilers fired with solid fuel (manufacturers' data),
$\eta_k$=0.85 for boilers fired with gas,
$\eta_k$=3.3 for heat pumps.

Table 3. Models of annual energy demand for preparation of hot usable water and meals in the tpu

| Specification | Empirical formula |
|---|---|
| Energy demand for preparation of hot usable water | $B_{cwu} = c_5 \cdot n_m \cdot \eta_{cwu}^{-1}$ |
| Energy demand for preparation of meals | $B_{pos} = c_6 \cdot Q_{pos} \cdot \eta_{pos}^{-1}$ |

where:
$n_m$ – number of residents [*Mk*],
$Q_{pos}$ – annual energy consumption for cooking in a household [*kW·h*],
$\eta_{cwu}$– efficiency of the equipment for heating water,
$\eta_{pos}$ – cooker efficiency,
$c_5$, $c_6$ – constants ($c_5$ = 0.051, $c_6$ = 0.000123).

The following values were used in further computations:
$\eta_{cwu}$=0.9 for electric equipment,
$\eta_{cwu}$=0.8 for gas-fired equipment,
$\eta_{cwu}$=0.5 for equipment fired with solid -fuel.
$\eta_{pos}$=0.7 for electric cookers,
$\eta_{pos}$=0.6 for gas cookers,
$\eta_{pos}$=0.5 for coal-fired cookers.

## MODEL VERIFICATION

The works carried out in the scope of verifying the model representing final energy consumption in a rural commune for heating of buildings and preparation of hot usable water and meals included the model accuracy and sensitivity testing. The model accuracy assessment was carried out on the grounds of the values of mean percentage errors (MPE) [Dittman 2005], by comparing total actual energy demand for individual consumer groups in the analysed communes to the demand values determined using drawn up relations. Computation results are compiled in Table 4. It was proven that these developed relations represented thermal energy consumption in farms and other buildings/facilities located in rural areas of Southern Poland with sufficient accuracy.

Table 4. Values of mean percentage errors for the models of thermal energy demand for individual consumer groups in rural communes

| Specification | MPE [%] |
|---|---|
| Sector of residential buildings | 2.4 |
| Sector of public buildings/facilities | - 4.1 |
| Sector of crops grown under covers | 4.5 |

The second verification criterion was the model sensitivity testing. The test involved developing several dozens of the model concepts for changing parameters. The tests were performed for few testing scenarios, which included taking into account the following: thermo-modernization of residential buildings, replacing coal-fired boilers with other types, or restructuring households due to the number of people living in them. A random-number generator for uniform distribution was used when drawing individual facilities intended e.g. for thermo-modernization. Fig.1 presents an example simulation result showing the effect of thermo-modernization operations on the size of final energy consumption in a commune. As you see, the model gave results forming a clear monotonic line after completed simulations. Similar outcome was obtained when implementing the other scenarios. This gave grounds to the statement that the developed model was formulated correctly.

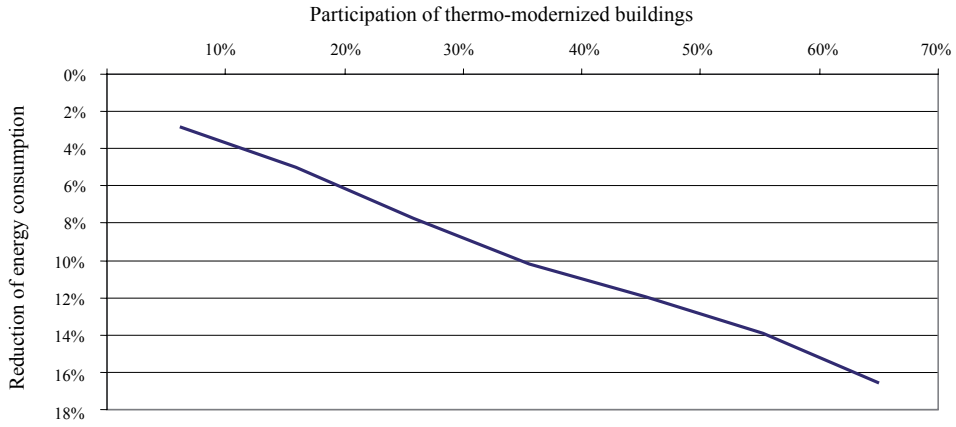


Fig. 1. Reduction of thermal energy consumption in a rural commune in function of total number of buildings subject to thermal modernization

## APPLICATION EXAMPLES

The developed model of energy consumption for heating of buildings and preparation of hot usable water and meals was applied to determine heat demand in individual communes in South-Eastern Poland. This provided grounds to determine heat demand in rural areas of Małopolskie, Podkarpackie and Świętokrzyskie Voivodships. In completed computations the researchers used statistical data compiled in the National Census [GUS 2003], General Farm Census [GUS 2003] and Statistical Yearbooks of Świętokrzyskie, Małopolskie and Podkarpackie Voivodships [GUS 2006].

Tab. 5 contains general characteristics of analysed voivodships, and table 6 shows results of computations for heat demand in individual voivodships. Fig. 2 presents the structure of this demand in rural areas of the analysed Voivodships.

Table 5. Characteristics for rural areas of the analysed voivodships

| Voivodship | Population of inhabitants [thousand of people] | Usable area of flats [thousand $m^2$] | Usable area of public facilities [thousand $m^2$] | Total area of covered crops [thousand $m^2$] |
|---|---|---|---|---|
| Małopolskie | 1605.5 | 33144.8 | 3242.9 | 585.1 |
| Podkarpackie | 1246.1 | 26162.5 | 1352.3 | 363.6 |
| Świętokrzyskie | 504.7 | 11817.9 | 2001.8 | 242.7 |
| Total | 3356.3 | 71125.2 | 6597.0 | 1191.4 |

Table 6. Annual demand for heat in rural areas of the analysed voivodships

| Voivodship | Sector of residential buildings [PJ] | Sector of public buildings [PJ] | Sector of crops grown under covers [PJ] | Total [PJ] | After-diversity demand GJ/Mk |
|---|---|---|---|---|---|
| Małopolskie | 41.62 | 2.75 | 0.98 | 45.35 | 28.25 |
| Podkarpackie | 30.25 | 1.29 | 0.64 | 32.18 | 25.82 |
| Świętokrzyskie | 12.46 | 2.08 | 0.50 | 15.04 | 25.93 |

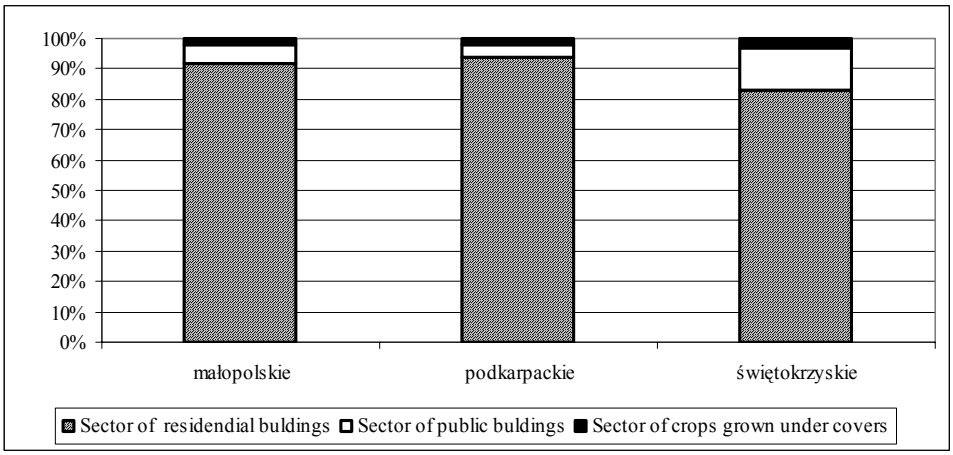


Fig. 2. Structure of thermal energy consumption in rural areas of South-Eastern Poland

## CONCLUSIONS

The developed model showing final energy demand for heating of buildings/facilities and preparation of hot usable water and meals is suitable for practical use in local planning of thermal needs in communes. This is so because it is based on data available in statistical statements of local governments, and completed tests prove that the model is formulated correctly and its quality is good (-5%<MPE<+5%).

Heat demand determined in this work for rural consumers in Małopolskie, Podkarpackie and Świętokrzyskie Voivodships may be used by local authorities of individual Voivodships in planning of heat supply within the territories they administer.

Heat demand in rural areas of South-Eastern Poland per single inhabitant is ca. 25.8 GJ in Świętokrzyskie and Podkarpackie Voivodships, and 28.2 GJ in Małopolskie Voivodship. On average for the analysed area, this index is near 26.7 GJ/Mk. Housing construction sector is the largest heat consumer, which receives almost 90% of total thermal energy demand in communes. Most of this energy (85%) is used for heating of rooms.

## REFERENCES

Dittman P. 2003: Prognozowanie w przedsiębiorstwie. Metody i ich zastosowanie. Oficyna Ekonomiczna, Kraków.

Gajda J.B. 2004: Ekonometria. Wydawnictwo C.H.Beck, Warszawa.

Kurpaska S. 2003: Ekonomiczno-ekologiczne aspekty stosowania elementów zmniejszających zużycie ciepła w tunelu foliowym. Problemy Inżynierii Rolniczej, 1, 47-56

Kurpaska S., Latała H. 2004: Wpływ wymiarów geometrycznych tunelu foliowego na jednostkowe zużycie ciepła. Inżynieria Rolnicza 4 (59), Tom II, 15-22.

Malko J. 1995: Wybrane zagadnienia prognozowania w elektroenergetyce. Prognozowanie zapotrzebowania energii i mocy elektrycznej. Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław.

Mróz T. 1999: Dotychczasowe doświadczenia w zakresie tworzenia planów zaopatrzenia w ciepło. III Ogólnopolska Konferencja pt. Planowanie energetyczne w mieście i gminie. Poznań 7-9 kwiecień, 85-102.

Robakiewicz M. 1999: Użytkowanie energii i oszczędności energii w budynkach. Narodowa Agencja Poszanowania Energii, Warszawa, 1-20.

Rocznik Statystyczny Województw 2006, GUS Warszawa.

Rocznik Statystyczny 2003: Wyniki Narodowego Spisu Powszechnego i Spisu Rolnego, GUS Warszawa.

Szul T. 2005: Wpływ wybranych działań racjonalizujących zużycie energii na poziom emisji zanieczyszczeń powietrza atmosferycznego w gminach wiejskich. Praca doktorska, Akademia Rolnicza w Krakowie.

Trojanowska M., Szul T. 2003: Techniczna i gospodarcza analiza oraz prognozowanie nakładów energetycznych na ogrzewanie budynków mieszkalnych na terenach wiejskich. Acta Scientiarum Polonorum. Technica Agraria 2 (2), Lublin, 69-77.

Trojanowska M., Szul T. 2006: Modelling of energy demand for heating buildings, heating tap water and cooking in rural households. TEKA Commission of Motorization and Power Industry in Agriculture, Lublin Vol. $VI_A$, 184-190.

Ustawa z dnia 8 marca 1990 r. O samorządzie terytorialnym Dz.U. z 1990 r. nr 13 poz. 74 z późn. zm.

Ustawa z dnia 10 kwietnia 1997 r. Prawo energetyczne Dz.U. z 1997 r. nr 54 z późn. zm.

Zabeltitz Ch. von. 1991: Szklarnie – projektowanie i budowa. Państwowe Wydawnictwo Rolnicze i Leśne, Warszawa.

## WYZNACZANIE POPYTU NA CIEPŁO W GMINACH WIEJSKICH

**Streszczenie.** W pracy przedstawiono model wspomagający planowanie i zarządzanie gospodarką energetyczną w gminach wiejskich w zakresie zapotrzebowania na ciepło. Przy pomocy modelu można określić zużycie energii finalnej na ogrzewanie, przygotowanie ciepłej wody użytkowej i posiłków we wszystkich obiektach znajdujących się na terenie gminy z błędem nie przekraczającym ±5%. Przedstawiony model wykorzystano do określenia popytu na ciepło przez odbiorców wiejskich z terenów Polski południowo-wschodniej.

**Słowa kluczowe:** planowanie energetyczne, zapotrzebowanie na ciepło, gmina wiejska.