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Potentials for energy savings and long term energy demands for Croatian households sector

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ABSTRACT

Households sector in Croatia represents one of the largest consumers of energy today with around 75,75PJ, which is almost 29% of Croatia's final energy demand. Considering this consumption, implementing different mechanisms that would lead to improvements in energy efficiency in this sector seems relevant. In order to plan future energy systems it is important to know future possibilities and needs regarding energy demand for different sectors. Through this paper long term energy demand projections for Croatian households sector will be shown with a special emphasis on different mechanisms, both financial, legal but also technological that will influence future energy demand scenarios. It is important to see how these mechanisms influence, positive or negative, on future energy demand and which mechanism would be most influential. Energy demand predictions in this paper are based upon bottom-up approach model which combines and process large number of input data. The Model will be compared to Croatian national Energy Strategy and certain difference will be presented. One of the major conclusions shown in this paper is significant possibilities for energy efficiency improvements and lower energy demand in the future, based on careful and rational energy planning. Different financial, legal and technological mechanisms can lead to significant savings in the households sector which also leads to lesser greenhouse gas emissions and lower Croatian dependence on foreign fossil fuels.

1. KEYWORDS

Future energy demand, households sector, energy efficiency, energy savings, bottom-up modelling

2. INTRODUCTION

Households sector presents one of the most important energy consumers in Croatia. With its 29% [18] of the whole Croatian final energy demand, households sector presents also a big opportunity for energy savings in the in upcoming period. Unfortunately, years of negligence, lack of building regulations and not obeying current building codes has lead to inefficient building stock with high energy consumption as a result. Considering its importance regarding national energy balances it would be very important to know what trends to expect in the households sector regarding future energy demand [1-4]. One of the key elements would be to analyze future energy demands depending on a few key elements influencing households sector: available surface increase, energy efficiency improvements and building codes regulations. This paper will present the connection between above mentioned elements and final energy demand of a household sector. In order to capture and quantify this connection a “Households Energy Demand Model” (HED Model) has been developed. HED Model is based on a bottom up approach analysis in order to quantify and describe all the key elements influencing energy demand in a more concise way [9-13]. Top down methodology or its fragments were also considered for this research [14-17] but its aggregated approach would not allow a precise combination and quantification of different elements and mechanisms that would influence energy demand [5-8]. HED Model is focused on calculating heating and cooling demand as well as energy demand for house appliances, hot water and cooking. Results and scenarios calculated and presented in this paper are compared to Croatian national energy strategy and certain conclusions are presented based on that comparison.

3. METHODOLOGY

HED Model is based on summarizing different sub-categories of households sector in order to get general overview image on energy consumption. This way deeper insight of a certain sub-category can be obtained in order to see differences in energy consumption dependent on different factors in a long period of time. HED Model is made for long term energy demand projections, in this paper till 2050, and is focused on final energy demand projections of Croatian households sector. In order to develop the methodology that would be used to model future energy demand certain sub-categories are introduced: space heating, appliances, hot water and cooking. Detailed description of above mentioned sub-categories and their specific properties will be presented in the following paragraphs.

3.1. Surfaces and population

In order to start modelling actual energy consumption and demand, first a detailed model that would predict the fluctuation of available surfaces of the households sector needed to be done. Modelling future available surfaces of Croatian households sector is made through available future population information available from Croatian Bureau of Statistics. Available future surfaces fluctuations are calculated for all 21 Croatian counties with the main parameters being population number and specific available surface:

$$A_i^z = P_i^z \cdot M_i^z \qquad (1)$$

Where: A_i - total available surface in a certain county (m^2), P_i- population of a certain county, M_i - specific available surface (m^2/person), z - year for which the calculation is made

Model calculates new available surface in the system and summarizes it in order to have precise information regarding surface distribution for the heat energy consumption calculation. Same principle goes for renovated buildings as well, with an exception of renovation paste index which is set by the user. Model calculates demolished surfaces for each year through historic index which can be imported in to the model by the user.

$$N_i^z = A_i^z - A_i^{z-1} + D_i^z \quad (2)$$

Where: N_i - new available surface in certain county (m^2), D_i - demolished surface in certain county (m^2)

$$R_i^z = A_i^{z-1} \cdot S \quad (3)$$

Where: R_i - renovated available surface in a certain county (m^2), S- renovation paste index

Population information and future fluctuation till 2050 are taken from Croatian Bureau of Statistic and they are not modelled but just imported as input information for HED Model.

3.2. Space heating and cooling

Calculating heat demand of an entire sector has proven to be a challenging task because of adjustments of all specific characteristics in calculating thermodynamic behaviour of an outside envelope applied to a whole sector. That is why HED Model first calculates energy consumption for the base year, which is set to 2007, because the output data is already known. This is also a way to calculate all unknown parameters which are later used in the model for the calculation of future energy demand.

3.2.1. Heat demand

Heat demand is determined based on the previously calculated available surface distribution among all Croatian counties which is combined with climatic information characteristic to a certain county. Base calculation of heat demand is made by deducting heat gains from heat losses. Heat losses are determined as heat transfer by transmission and ventilation while heat gains are determined as solar heat gains and internal heat gains.

$$Q_i^z = (Qt_i^z + Qv_i^z) - (Qs_i^z + Qi_i^z) \quad (4)$$

Where: Q_i - total heat demand (PJ), Qt_i - heat transfer due to transmission (PJ), Qv_i - heat transfer due to ventilation (PJ), Qs_i - solar heat gains (PJ), Qi_i - internal heat gains (PJ)

Calculation is based on monthly procedure which roughly follows ISO 13790 [19] norm for energy performance of buildings. Heat transfer due to transmission is based on outside envelope surfaces which are calculated based on available surfaces, thermal transmittance and temperature differences.

$$Qt_i^z = h^z \cdot Ae_i^z \cdot U_i^z \cdot \Delta T_i^z \cdot t \quad (5)$$

Where: h - share of heated space, Ae_i - available envelope surface (m^2), U_i - thermal transmittance (kW/m^2K), ΔT_i - temperature difference between outside monthly average temperature and inside temperature (K), t - duration of calculation step (h)

When calculating available envelope surface, user can define the ratio between windows and walls as well as future improvements regarding the envelope. Future improvements are set through different thermal transmittance factors for walls and windows for every year of the calculation. Temperature difference for every county is based on real climatic data which are imported into the model. Heat transfer due to ventilation is calculated primarily based on air exchange rate which is subject to modification by the user.

$$Qv_i^z = \rho \cdot cp \cdot q^z \cdot \Delta T_i^z \cdot t \qquad (6)$$

Where: ρ - air density (kg/m^3), cp - air heat capacity (J/kgK), q^z - airflow (m^3/h)

Internal heat gains are calculated based on the ISO 13790 norm [19] which regulates internal heat gains per square meter of residential space while solar heat gains are based on window surfaces and solar radiations which is a subject of geographical location, in this case one of 21 Croatian counties.

$$Qs_i^z = c^z \cdot Aw_i^z \cdot g \cdot af_i \cdot ps_i \cdot I_i \cdot t \qquad (7)$$

Where: Aw_i - effecting collecting area (m^2), g - solar energy transmittance of transparent element, af_i - frame reduction factor, ps_i - shading reduction factor, I_i - solar irradiance (kW/m^2)

3.2.2. Cooling demand

Cooling demand through HED Model is calculated based on cooling degree days since this method turned out to be the most appropriate for calculating whole residential sector. This methodology was used because following previously presented methodology used for heating demand didn't produce satisfying results when observing cooling demand.

$$Qc_i^z = c^z \cdot Ae_i^z \cdot U_i^z \cdot Dd_i^z \qquad (8)$$

Where: c - share of surface cooled, Dd_i - cooling degree days

As well as in calculating heat demand, user can set the ratio between windows and walls as well as set the thermal transmittance for both windows and walls for future period as a result of envelope improvements.

3.3. Electronic appliances

Electronic appliances are divided into: large appliances, small appliances and lightning. This type of division is made based on different databases [21] in order to follow existing methodology and consumption results and data. Based on this methodology air-conditioning goes to large appliances category and is calculated separately since cooling demand is calculated inside the HED Model. In this case base year calculations are essential in determining starting input data and calibrating it with available literature information. HED Model can calculate energy consumption and future energy demand both through available surfaces as well as population information. For the purposes of this paper surface calculation is used. The first step of the calculation is that the Model calculates starting values that are verified through base year of the calculation. Afterwards user can set the energy efficiency improvements for specific consumption for future period.

$$E_i^z = sp_i^z \cdot l_i^z \cdot A_i^z \qquad (9)$$

Where: E_i - final energy consumption of a certain electric appliances category (PJ), sp_i - specific consumption of a certain electric appliances category (kWh/m^2), l_i - energy efficiency improvements index in a certain year

Since cooling demand is calculated through the HED Model final energy consumption for space cooling is calculated through coefficient of performance index which is also set by the user as well as potential future improvements.

$$Ea_i^z = Qc_i^z / COP_i^z \qquad (10)$$

Where: Ea_i-final energy consumption for space cooling (PJ), COP_i- coefficient of performance index

This way user can calculate how future technology improvement would influence on final energy demand for space cooling.

3.4. Hot water

Hot water demand is calculated based on the EN 15316-3-1 [22] norm that gives calculation process for calculating energy demand for hot water in households. Norm states specific consumption per a square meter which is incorporated into the model as an input data. In this case only energy demand is calculated while final energy demand is calculated based on different technologies and their efficiencies. Fuel mixing is described in a more detailed way in the following paragraphs.

3.5. Cooking

Final energy demand for cooking is calculated based on the same methodology used for electrical appliances with the difference of fuel mix which is here calculated separately. Initial data for final energy consumption for cooking is information received based on poll information. This poll information is tested through the base year and it turned out to be valid and correct information. Regarding fuel consumption in this category primary mix is combined from electricity and gas. Methodology for the fuel mixing is described in the fuel mix chapter.

3.6. Fuel mixes

HED Model has a separate fuel mix module which combines energy efficiency of a certain technology and share ratio of a certain fuel type in the final fuel distribution of a certain sub-category. This module is necessary for calculating final energy demand for heating, hot water and cooking. Through this module user can combine different technologies and fuel types in a scenario approach in order to compare different strategies regarding future energy demand planning. Starting energy mixes are calculated based in the input data for the base year. User can set the paste of efficiency and fuel ration change for every year till year 2050. With efficiency and fuel ratio for every technology and fuel type final energy demand for previously mentioned categories is calculated.

$$F_i^z = \sum_{i=1}^{n} fd_i^z \cdot ee_i^z \cdot r_i^z \tag{11}$$

Where: F_i - final energy demand (PJ), fd_i - energy demand (PJ), ee_i - energy efficiency index, r_i - share ratio of a certain fuel type index

As already mentioned this methodology is used for calculating final energy demand for heating, hot water and cooking.

4. RESULTS

One of the main intentions for this paper was to see the influence of future energy regulations regarding refurbishments and building zero energy buildings at a certain year in the future. On Fig. 1 heat demand of reference scenario is presented with refurbishment rate of 1% yearly and introduction of all new building entering the system as “zero-energy buildings” after year 2021. All building refurbished after 2026 are also considered as “zero energy” buildings. This of course means they still consume energy but that energy has to be produced locally from renewable energy source; this is presented by marked surface in Fig. 1).

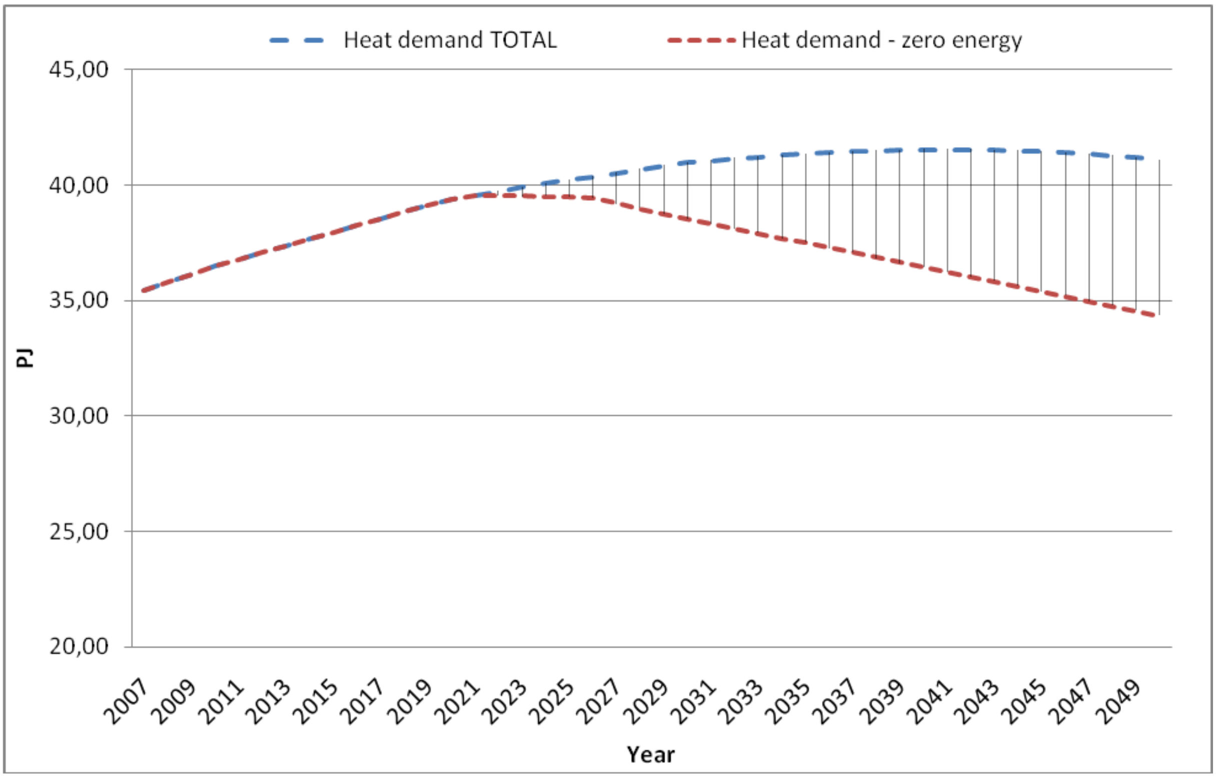

Figure 1 – Heat demand for the reference scenario

Other vital issue is the refurbishment paste which also directly influences future heat demand. On Fig. 2 different heat demands are presented depending on the applied refurbishment yearly paste.

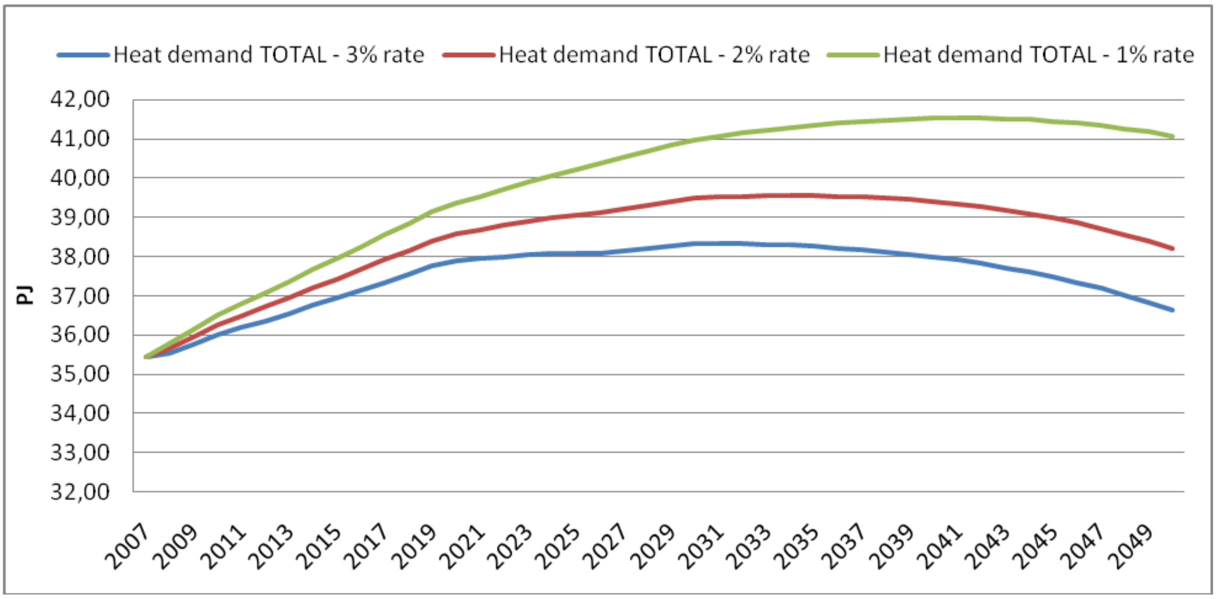

Figure 2 – Total heat demand depending on different refurbishment yearly rates

Results connected to heat demand are presented because space heating is the highest energy consumer of Croatian households sector with 57% [18]. On Fig. 3 reference scenario with final energy demand of all sub-categories is presented. Reference scenario is modelled based on current building codes and with the presumption that people are complying with current building codes strictly. Reference scenario on Fig. 3 presents final energy demands together with new and refurbished "zero energy buildings" energy demand.

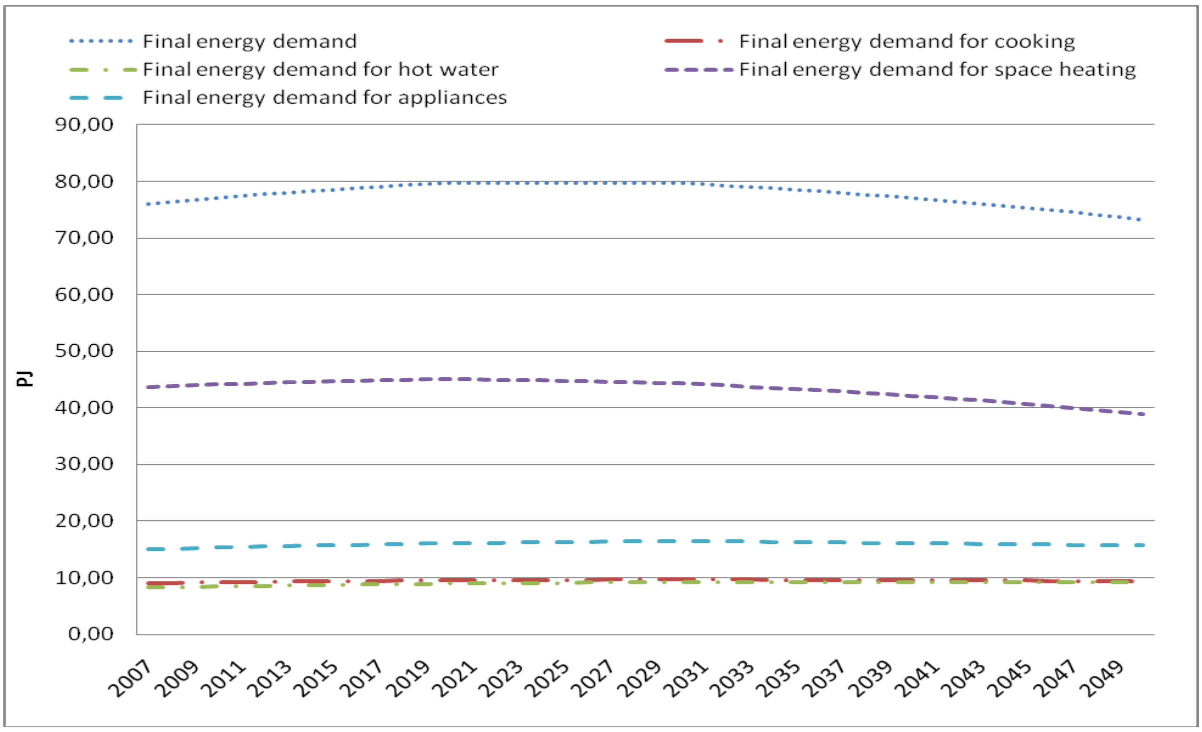

Figure 3 – Final energy demand - Reference scenario

As already mentioned in the introduction this paper presents the comparison of official Croatian national energy demand projections with the results of HED Model. On Fig. 4 National demand projections are compared with the HED Model reference scenario [20].

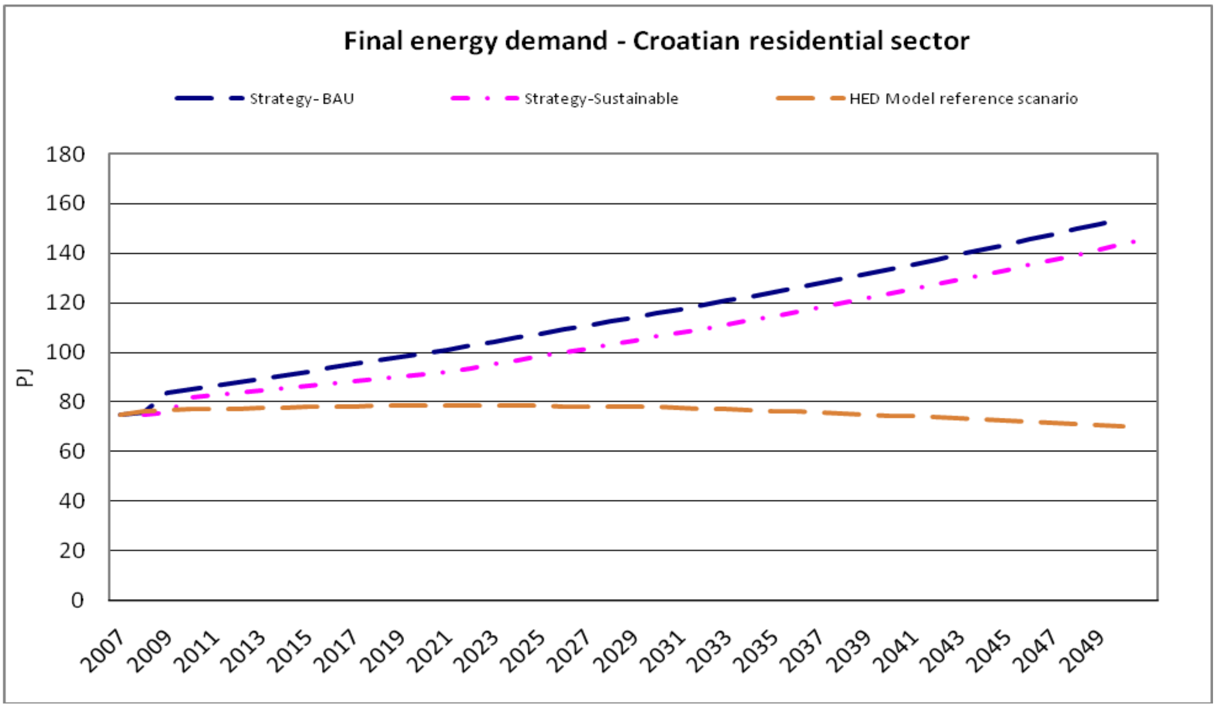

Figure 4 – Final energy demand projections comparison

When testing HED Model three future energy demand scenarios are made for the purposes of this paper: biomass option, district heating option and heat pumps option. These options are applied to space heating section while other sub-categories are set to reference scenario values. On Fig. 5 biomass scenario is presented regarding energy demand while Fig. 6 gives share ratios of different fuels of the same scenario.

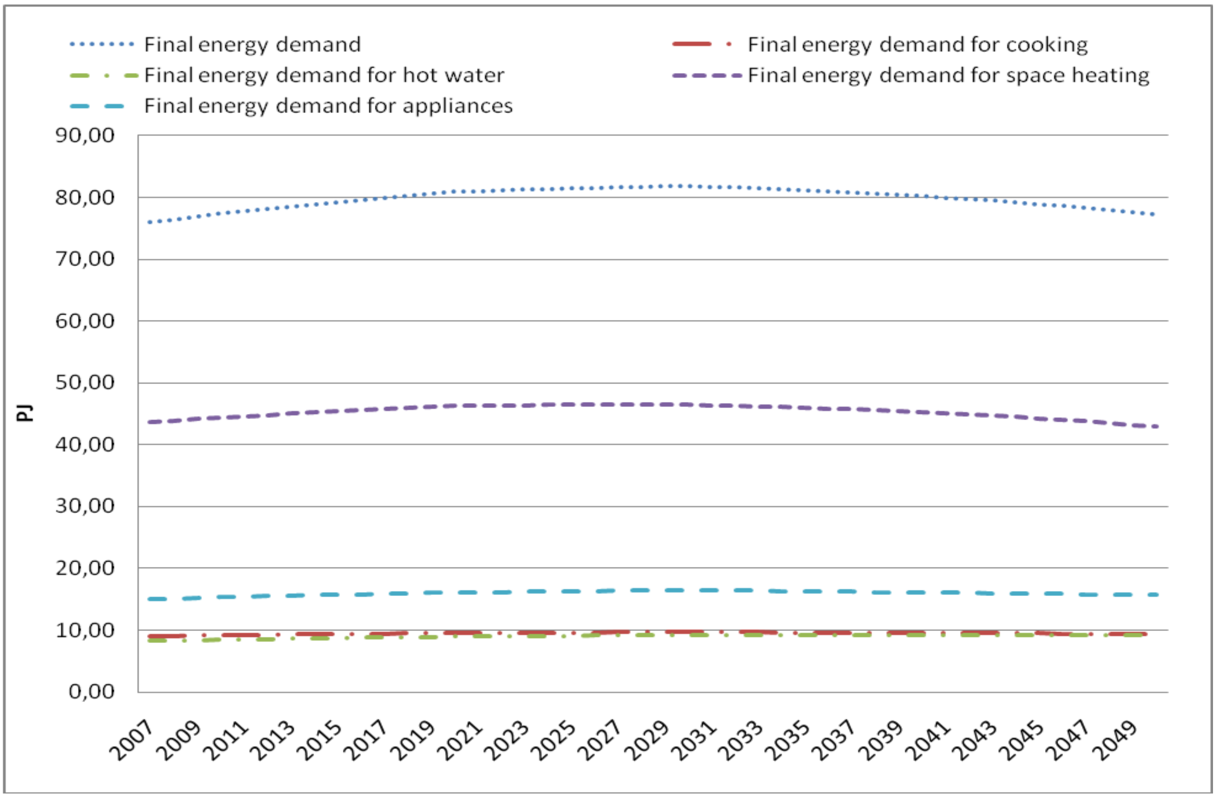

Figure 5 – Final energy demand - biomass options

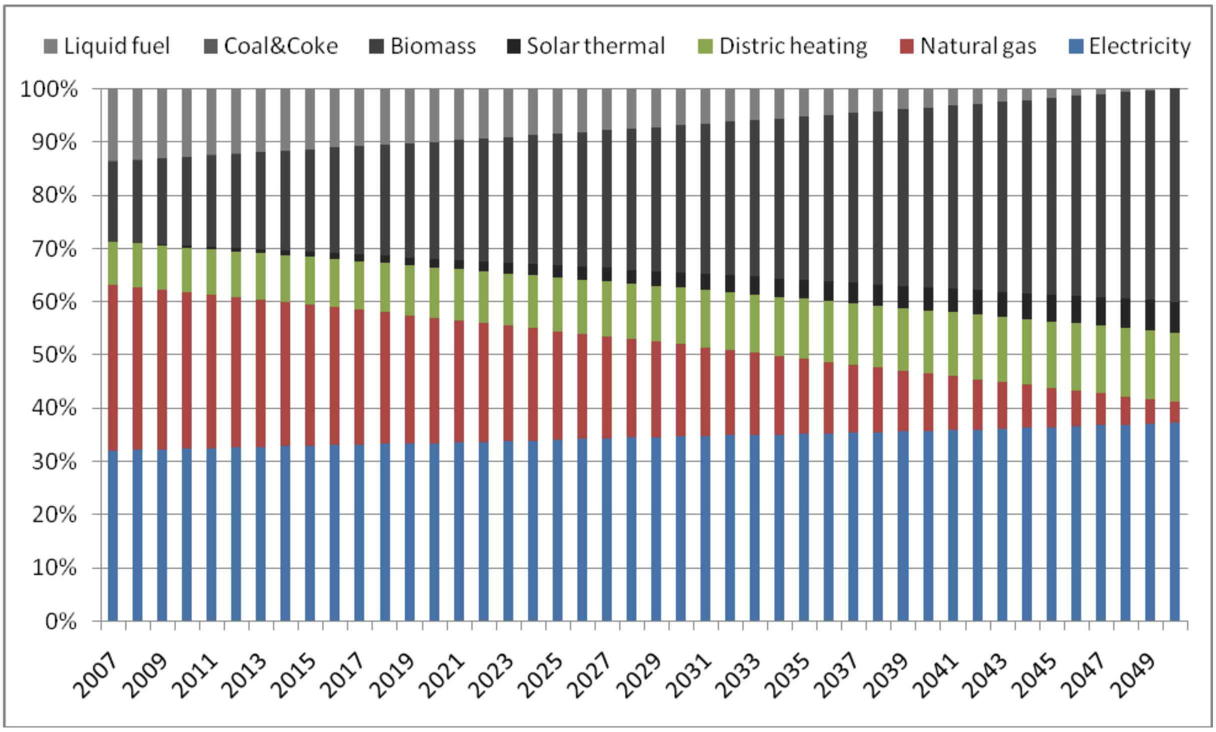

Figure 6 – Fuel share for biomass option

Similar situation happens with district heating option regarding final energy demand (Fig. 7) while fuel shares changes in favour for district heating (Fig. 8).

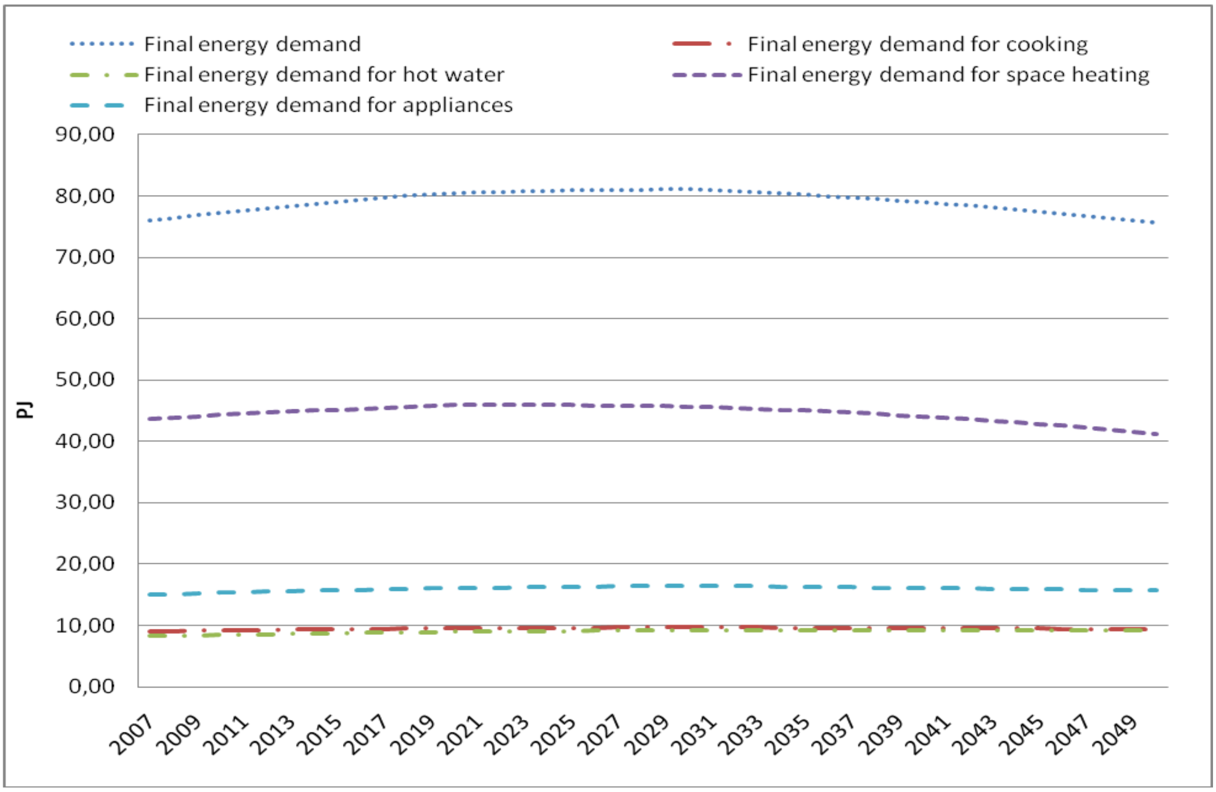

Figure 7 – Final energy demand – district heating option

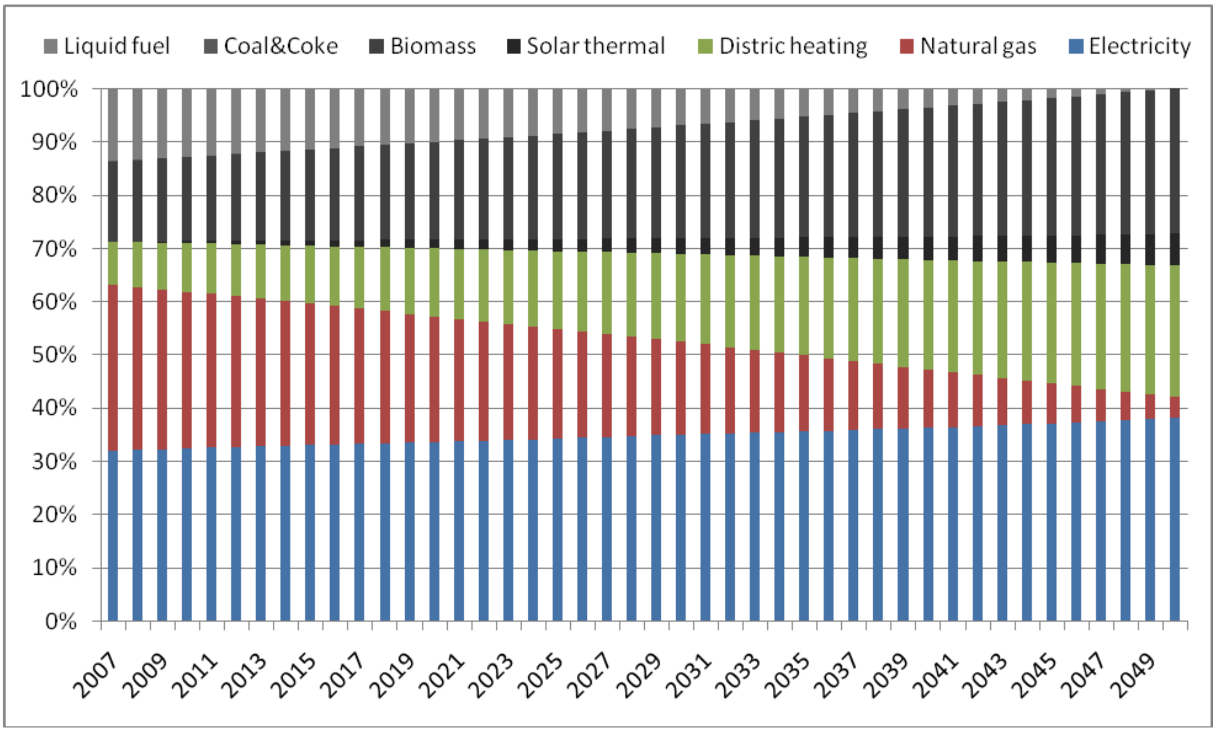

Figure 8 – Fuel share for district heating option

As seen from the results (Fig. 9) high penetration of heat pumps for space heating leads to significant decrease of final energy consumption in the households sector.

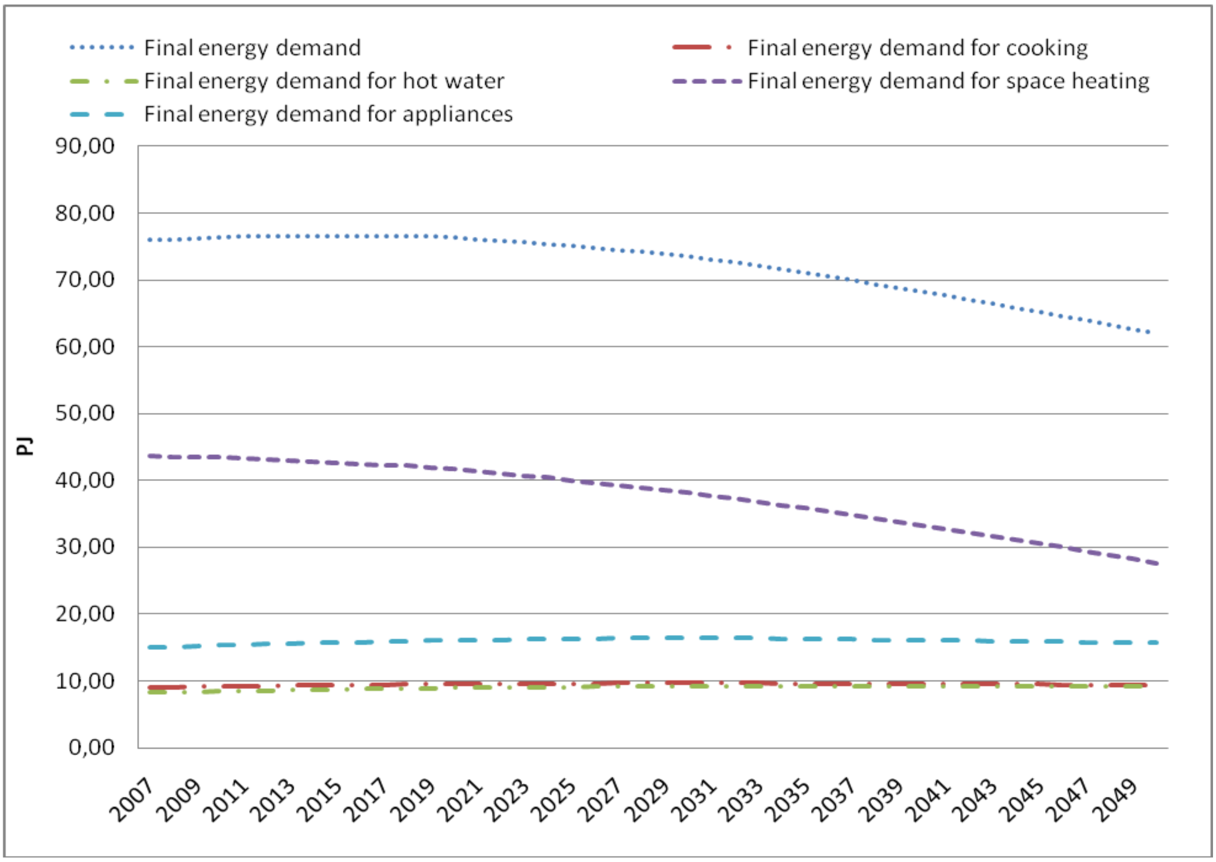

Figure 9 – Final energy demand – heat pumps option

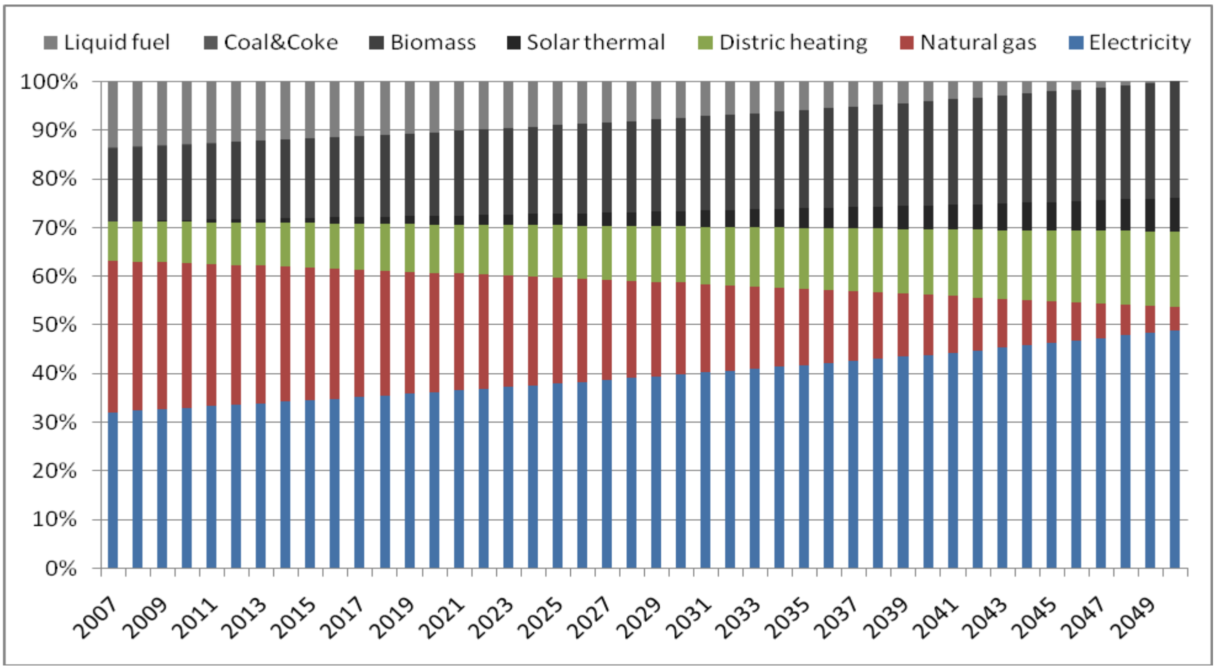

Figure 10 – Fuel share for heat pumps option

High penetration of heat pumps also leads to an increase of electrical energy consumption in the future period but this is electricity that could also be produced locally and from renewable energy sources. It is clear that future building stock tending to be passive or zero energy will have a hard time achieving this without heat pumps.

5. CONCLUSION

As seen from the results households sector presents a big opportunity for energy savings and penetration of renewable sources in the future. One of the key elements is enforcing current building codes for all buildings that are being built or refurbished. Applying these codes strictly would lead to significant energy savings. One of the key elements regarding energy consumption in the households sector would be introducing new regulations that would require new and refurbished building to produce their energy locally, or to be zero energy houses. For Croatian households sector, turning heavily to biomass, heat pumps and district heating seems the most logical choice for the future. One of the conclusions drawn from the presented results is the fact that Croatian national energy demand scenarios regarding households sector needs to be considered with a certain reserve since bottom up modelling shows a certain room for energy savings improvements.

6. NOMENCLATURE

A_i - total available surface in a certain county (m^2)

P_i - population of a certain county

M_i - specific available surface (m^2/person)

z - year for which the calculation is made

N_i - new available surface in certain county (m^2)

D_i - demolished surface in certain county (m^2)

R_i - renovated available surface in a certain county (m^2)

S- renovation paste index

Q_i - total heat demand (PJ)

Qt_i - heat transfer due to transmission (PJ)

Qv_i - heat transfer due to ventilation (PJ)

Qs_i - solar heat gains (PJ)

Qi_i - internal heat gains (PJ)

h - share of heated space

Ae_i - available envelope surface (m^2)

U_i - thermal transmittance (kW/m^{2}K)

ΔT_i - temperature difference between outside monthly average temperature and inside temperature (K)

t - duration of calculation step (h)

ρ - air density (kg/m^3)

cp - air heat capacity (J/kgK)

q^z - airflow (m^3/h)

Aw_i - effecting collecting area (m^2)

g - solar energy transmittance of transparent element

af_i - frame reduction factor

ps_i - shading reduction factor

I_i - solar irradiance (kW/m^2)

c - share of surface cooled

Dd_i - cooling degree days

E_i - final energy consumption of a certain electric appliances category (PJ)

sp_i - specific consumption of a certain electric appliances category (kWh/m^2)

l_i - energy efficiency improvements index in a certain year

Ea_i -final energy consumption for space cooling (PJ)

COP_i - coefficient of performance index

F_i - final energy demand (PJ)

fd_i - energy demand (PJ)

ee_i - energy efficiency index

r_i - share ratio of a certain fuel type index

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