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Potentials for energy savings and long term energy demand of Croatian households sector

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HIGHLIGHTS

- ▶ Long term energy demand of Croatian households sector has been modelled.
- ▶ Developed model can describe the whole households sector.
- ▶ Main modes include heating, cooling, electrical appliances, cooking and hot water.
- ▶ Different scenarios regarding future energy demand are presented and discussed.

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ABSTRACT

Households represent one of the most interesting sectors, when analyzing Croatia's energy balance. It makes up one of the largest energy consumers with around 75 PJ per year, which is almost 29% of Croatia's final energy demand. Considering this consumption, implementing various mechanisms, which would lead to improvements in energy efficiency of this sector, seems relevant. In order to plan future energy systems, important would be to know future possibilities and needs regarding energy demand of different sectors. Through this paper, long term energy demand projections of Croatian households sector will be shown. Focus of the paper will be on various mechanisms influencing future energy demand scenarios. Important would be to quantify this influence, whether positive or negative, and see which mechanisms would be the most significant. Energy demand projections in this paper are based upon bottom-up approach model which combines and processes a large number of input data. The model will be compared to Croatian National Energy Strategy and certain differences and conclusions 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 leads to lower GHG emissions and lower Croatian dependence on foreign fossil fuels.

1. Introduction

With such an importance to the Croatian energy balance [1], households sector presents a significant opportunity for energy savings and implementation of renewable energy sources in the upcoming period. According to [2], decentralized energy generation, with special emphasis on households, would become an important factor in wider introduction of renewable energy sources. Energy efficiency wise, years of negligence, lack of building regulations and disobeying current building codes has lead to inefficient building stock with high energy consumption as a result. However certain improvements in this field are noticeable in the last years. These trends are mostly influenced by Croatian accession to the EU. Consequential to this process is the transposition of all EU legislation regarding energy performance of buildings. As in the Italian case, Croatian decision makers need to perceive the benefits of current building stock improvements and introduction of low energy buildings as a mechanism in achieving significant energy savings [3]. This should be observed as a great opportunity since it will allow further development of Croatian economy and better energy management in the households sector. Although financial benefits, which would be the result of EPBD[1] implementation in Croatia, are not the subject of this research, their impact on country's economy could be significant [4].

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[1] Energy performance of buildings directive.

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Nomenclature

A_i	total available floor area in a certain county (m^2)	t	duration of calculation step (h)
P_i	population of a certain county	he	average height of heated floor area (m)
M_i	specific available floor area (m^2/person)	n_{ex}	air exchange rate (s^{-1})
z	year for which the calculation is made	ρ	air density (kg/m^3)
N_i	new available floor area in certain county (m^2)	cp	air heat capacity (J/kgK)
D_i	demolished floor area in certain county (m^2)	q^z	airflow (m^3/h)
R_i	renovated available floor area in a certain county (m^2)	Aw_i	effecting collecting area (m^2)
		g	solar energy transmittance of transparent element
S	renovation paste index	af_i	frame reduction factor
tR_i	total renovated building stock (m^2)	ps_i	shading reduction factor
tN_i	total new building stock (m^2)	I_i	solar irradiance (kW/m^2)
Bs_i	"old" building stock (m^2)	c	share of floor area cooled
Q_i	total heat demand (PJ)	Qc_i	total cooling demand (PJ)
Qt_i	heat transfer due to transmission (PJ)	Dd_i	cooling degree days
Qv_i	heat transfer due to ventilation (PJ)	E_i	final energy consumption of a certain electric appliances category (PJ)
Qs_i	solar heat gains (PJ)		
Qi_i	internal heat gains (PJ)	sp_i	specific consumption of a certain electric appliances category (kWh/m^2)
h	share of floor area heated		
v	wall percentage of available envelope surface (%)	l_i	energy efficiency improvements index in a certain year
w	window percentage of available envelope surface (%)	Ea_i	final energy consumption for space cooling (PJ)
vU_i	thermal transmittance for walls (kW/m^{2}K)	COP_i	coefficient of performance index
wU_i	thermal transmittance for windows (kW/m^{2}K)	F_i	final energy demand (PJ)
Ae_i	available envelope surface (m^2)	fd_i	energy demand (PJ)
ΔT_i	temperature difference between outside monthly average temperature and inside temperature (K)	ee_i	energy efficiency index
		r_i	share ratio of a certain fuel type index

Considering all possible measures that could be implemented in Croatian households sector, it would be very important to know what trends to expect regarding future energy demand. This would also be important in terms of satisfying international commitments regarding energy consumption and GHG emission [5] as well as planning future energy systems. Modelling long term energy demand is the first step towards advanced energy systems analysis since its results presents one of the key input data used for energy systems optimization [6,7]. In order to plan sustainable and energy efficient energy systems, including households sector, precise energy demand projection is crucial [8,9].

One of the key elements of this research would be to analyze future energy demands depending on most interesting characteristics specific to households sector: available floor area increase, energy efficiency improvements and building code regulations. There are other elements whose influence on future energy demand could be significant, like occupants' activity and their behavioural patterns [10]. These elements can be very interesting in cases where heating demand is not predominant [11]. This paper will present the connection between above mentioned elements and final energy demand of a household sector. In order to 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 [12]. Because of that, technology impact, as well as energy policy, could be quantified and later on compared.

Based on available literature, statistical and engineering bottom up modelling are the two most common approaches [13]. While statistical bottom up approach is not the focus of this research we will just mention its value in processing vast quantity of historical data, usually using regression analysis. But when considering any kind of technology impact, bottom up analysis based on engineering approach that could describe building physics is needed. This includes different referent units, from individual sample buildings till wider geographic units, like neighbourhoods [14]. HED model works with three basic referent units used for energy consumption calculation: newly built, refurbished and existing "old" units. All three units are represented with available floor area and are distributed geographically in 21 Croatian counties. At the same time HED model uses different statistical components which are based solely on empirical information which could classify it as a hybrid model [15]. If we compare it with IEA World Energy Model specific for households sector [16], many methodological connections could be found. Calculation logic is similar when compared to HED model, in terms of end use distribution and partially regarding activity variables. Based on IEA methodology, socio-economic drivers are defined in a far more detailed way which allows better interaction between energy demand and prices.

Bottom up approach has his flaws in a form of large number or input data that is required when establishing a base year of the calculation. This is very often combined with a lot of average figures or measured data which could influence final results considerable. Other issue is the behavioural influence on energy demand and its description and quantification. Bottom up models often do not model, but just assume behavioural impact on energy consumption, which is a clear shortcoming of this approach [13]. HED model is in line with this statement with one exception which is the demographic parameter. Based on the demographic fluctuation and its geographic distribution, HED model has an initial possibility to describe occupants' activities, but further development is necessary. Proposed action could go towards better integration of top down and bottom up approach with the integration of possible macroeconomic indicators. Finally, sectoral integration and interaction could present an obstacle when considering significant quantity of input data. Sectoral approach gives more detailed overview of basic modelled data, such as building stock, but it lacks the capacity for inter-sectoral interaction [17]. But since HED model does not work as an optimization model this shortcoming will not be an issue in our case.

More detailed application of top down methodology or its fragments were considered for this research but its aggregated approach would not allow a precise combination and quantification of different elements and mechanisms that would influence energy demand [13].

HED model is focused on calculating heating and cooling demand as well as energy demand for house appliances, hot water and cooking. One of the main intentions was to show how can renovation paste influence on future energy demand. In our case intention was to show the influence of new zero energy buildings and old buildings renovated to zero energy standard on final energy demand [18]. With such a detailed model, different improvements regarding energy efficiency as well as different technologies and fuel mixes could be presented and discussed. The idea is to connect demographics and available floor area of the whole households sector with its final energy demand. Based on this connection different scenarios and approaches could be presented. Calculated results and scenarios are compared to Croatian National Energy Strategy. HED model can be used for any other country and its households sector, considering all the specificness of that country. Model works based on the population data, floor area, specific climatic regions which can all be imported into the model. Since HED model is MS Excel based, every user can modify all the categories based on its needs. The same is with specific energy efficiency improvements. The only shortcoming of this approach is the extensive input data required, which could present a problem for using the model on a different country. Regarding tertiary sector, HED model could also be used although deeper modifications would be necessary, but the basic methodology regarding energy demand calculation can be applied.

2. Methodology

HED model is based on summarizing different sub-categories of households sector in order to get an overview of its energy consumption. By segregating the entire sector, deeper insight of an each sub-category can be obtained in order to see the differences in future energy consumption, which are dependent on various factors and mechanisms. HED model is made for long term energy demand projections, in this paper till 2050, and is focused on presenting final energy demand of Croatian households sector. Various sub-categories, in this case modes, are introduced in order to describe all the specificness of energy consumption of a households sector: space heating, electric appliances including space cooling, hot water and cooking. Basic overview of all main modes and their interaction are presented on Fig. 1. Detailed description of all sub-categories, or modes, and their specific properties will be presented in the following paragraphs.

2.1. Floor area and population

In order to start modelling the actual energy consumption and demand, first a detailed mode that would predict the fluctuation of available floor area of the households sector had to be developed. Modelling future available floor area of Croatian households sector is made by using available future population information available from Croatian Bureau of Statistics (DZS) [27]. Population mode is structured in order to describe possible migration trends. These trends are visible in Croatian case with clear migration toward major cities and the nation's capital. This geographical population shift could lead to significant difference in energy demands. Every user can modify HED model and set the parameters of migration. First possibility is to presume constant geographic ratio regarding population and the second one is to model specific migration trends for every future year. Population information and future fluctuation till 2050, on an aggregated national scale, are taken from Croatian Bureau of Statistics (DZS) so they are not modelled but just imported as input data into the HED model.

As seen on Fig. 1 available floor area and their future fluctuation is one of the key parameter of the HED model. It presents an input for the rest of the energy related modes. Model also has the ability to take into consideration various building types and calculate future available floor area trends. The main categories include: permanently occupied dwellings and partially occupied dwellings. This methodology could be further divided, depending on the available input data. As a backup solution, in the case of limited input data, model has the possibility of working with the total available floor area of every county which is then modified in the following modes by the occupancy indexes. This is done by modelling a base year, which is chosen by the user. This step allows for all the input data to be tested and verified. Available future floor area fluctuations are calculated for all 21 Croatian counties with population data and specific available floor area as main parameters:

$$A_i^z = P_i^z \cdot M_i^z \tag{1}$$

where: A_i is the total available floor area in a specific county (m^2), P_i the population of a specific county, M_i the specific available floor area of a specific county (m^2/person), and z is the year for which the calculation is made.

The model calculates new available floor area in the system and summarizes it in order to have precise information regarding floor area distribution for the heating and cooling energy consumption calculation. Same principle is applied for renovated buildings, with an exception of renovation paste index which is set by the user. Model calculates demolished floor area for each year through historic index which can be imported into the model by the user.

$$N_i^z = A_i^z - A_i^{z-1} + D_i^z \tag{2}$$

where: N_i is the new available floor area in certain county (m^2) and D_i is the demolished surface in certain county (m^2)

$$R_i^z = A_i^{z-1} \cdot S \tag{3}$$

where: R_i is the renovated available floor area in a certain county (m^2) and S is the renovation paste index

$$tR_i^z = tR_i^{z-1} + R_i^z$$

where: tR_i is the total renovated building stock (m^2)

$$tN_i^z = tN_i^{z-1} + N_i^z$$

where: tN_i is the total new building stock (m^2)

$$Bs_i^z = A_i^z - tN_i^z - tR_i^z$$

where: Bs_i is the "old" building stock (m^2),

Floor area that is renovated or newly built is calculated on a yearly basis, for a specific year (N_i and R_i). However HED model tracks and calculates total floor area which is newly built or renovated in every county for every specific year (tN_i and tR_i). The same principle applies to the total number regarding floor area for every county that is still not being renovated. The final outcome of the Floor area mode is detailed overview and information on available floor area of all building categories for every geographic unit, in our case all 21 Croatian counties. Model calculates specific available floor area based on all of the imported data referring to the base year. Afterwards user can set a paste of specific available floor area fluctuation for every geographic unit. This way user can describe current trends of increasing the living area per a resident.

2.2. Space heating and cooling

Calculating heat demand has proven to be a challenging task because of adjustments and all specific characteristics in calculating thermodynamic behaviour of an outside envelope, applied to an

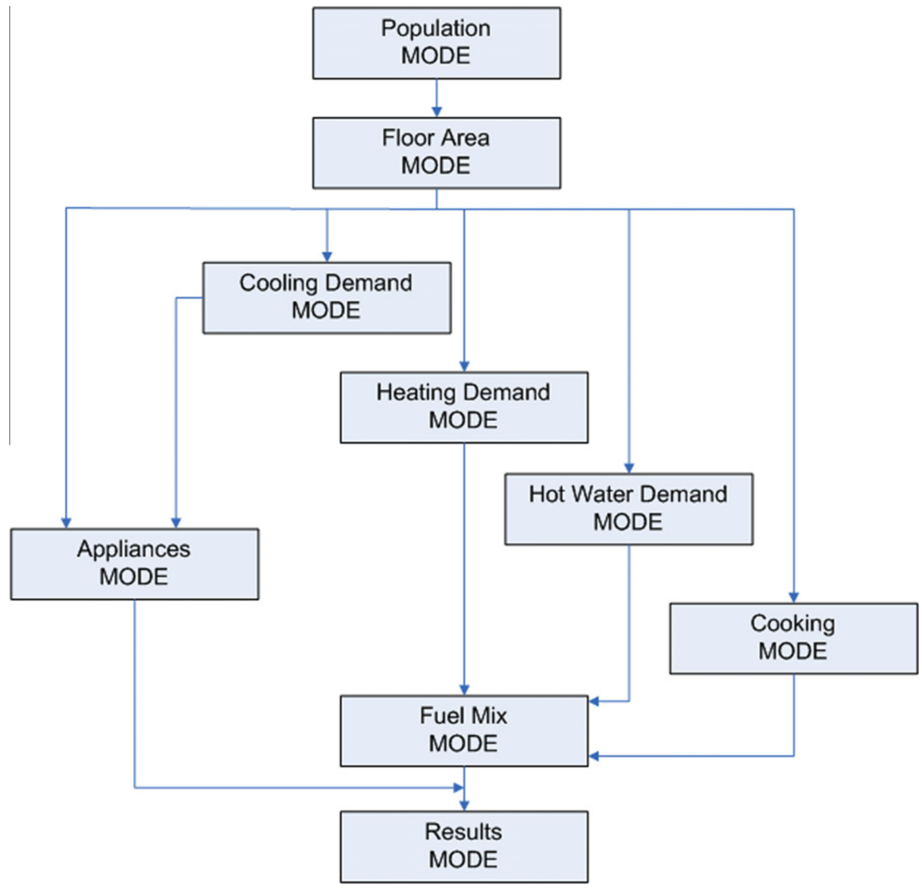

Fig. 1. Basic overview of HED model modes.

entire sector. That is why HED model calculates energy consumption for the base year in order to test the methodology and all input parameters and factors. For the purposes of this research, base year is set to 2008. Testing the methodology on a base year is convenient since energy consumption, in this case output data, is already known. This is also a way to calculate and verify all unknown parameters which are later on used in the model for the calculation of future energy demand.

2.2.1. Heat demand

Heat demand is determined based on the previously calculated available floor area distribution among all Croatian counties which is combined with climatic information characteristic to a specific 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.

$$Q_i^z = (Qt_i^z + Q\,v_i^z) - (Qs_i^z + Qi_i^z) \tag{4}$$

where: Q_i is the total heat demand (PJ), Qt_i the heat transfer due to transmission (PJ), Qv_i the heat transfer due to ventilation (PJ), Qs_i the solar heat gains (PJ), and Qi_i is the 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 floor area, thermal transmittance and temperature differences. Every geographic unit is given a reference climatic constrains that are used to calculate transmission losses.

$$Qt_i^z = (h^z \cdot v \cdot Ae_i^z \cdot vU_i^z \cdot \Delta T_i^z \cdot t) + (h^z \cdot w \cdot Ae_i^z \cdot wU_i^z \cdot \Delta T_i^z \cdot t) \tag{5}$$

where: h is the share of heated space, v the wall percentage of available envelope surface (%), Ae_i the available envelope surface (m^2), w the window percentage of available envelope surface (%), vU_i the thermal transmittance for walls (kW/m^2K), wU_i the thermal transmittance for windows (kW/m^2K), ΔT_i the temperature difference between outside monthly average temperature and inside temperature (K), and t is the 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. This way all energy efficiency initiatives are describable and quantifiable for every year. 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. HED model calculates exchanged airflow based on available floor area, percentage of heated floor area, average height of heated floor area and air exchange rate.

$$q^z = h \cdot A_i^z \cdot he \cdot n_{ex}$$

where: he is the average height of heated floor area (m) and n_{ex} is the air exchange rate (s^{-1})

$$Q\,v_i^z = \rho \cdot cp \cdot q^z \cdot \Delta T_i^z \cdot t \tag{6}$$

where: ρ is the air density (kg/m^3), cp the air heat capacity (J/kgK), and q^z is the airflow (m^3/s).

Internal heat gains are calculated roughly following 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 irradiance which is a subject of geographical location.

$$Qs_i^z = c^z \cdot Aw_i^z \cdot g \cdot af_i \cdot ps_i \cdot I_i \cdot t \tag{7}$$

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

2.2.2. Cooling demand

Cooling demand is calculated based on cooling degree days since this method turned out to be the most appropriate for calculating whole households sector. This methodology was used because methodology used for heating demand, which was tested through the base year consumption, did not produce satisfying results when applied to cooling.

$$Qc_i^z = (c^z \cdot v \cdot Ae_i^z \cdot vU_i^z \cdot Dd_i^z) + (c^z \cdot w \cdot Ae_i^z \cdot wU_i^z \cdot Dd_i^z) \tag{8}$$

where: Qc_i is the total cooling demand (PJ), c the share of floor area cooled, and Dd_i is the cooling degree days.

As well as in calculating heat demand, the 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. Share of cooled floor area can be modified for every year allowing users to describe the possible energy consumption increase in air conditioning which is an important issue in Croatia.

2.3. Electronic appliances

Electronic appliances are observed from the point of electricity consumption and are divided into: large appliances, small appliances and lightning. This type of division is made based on various databases [20] in order to follow existing methodology and compare consumption results and data. Based on this methodology air-conditioning is a part of large appliances category and its electricity consumption is calculated separately in order to use data retrieved through Cooling demand mode. In this case base year calculations are essential in determining starting input data and calibrating it with available literature information. In order to present total electricity used in the households sector, electricity used for space heating, cooking and hot water is added to electricity used by electronic appliances in the final Results mode (Fig. 1).

HED model can calculate energy consumption and future energy demand both through available floor area as well as population information. For the purposes of this paper floor area calculation is used. First step of this calculation includes determining the starting values that are verified through the input data of a chosen base year. Afterwards user can set the energy efficiency improvements regarding specific consumption for the future period.

$$E_i^z = sp_i^z \cdot l_i^z \cdot A_i^z \tag{9}$$

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

Since cooling demand is previously determined through the Cooling demand mode, final energy consumption for space cooling is calculated through coefficient of performance index. Electricity is presumed as a single "fuel" used to satisfy cooling demand. Further research on additional fuel forms that could satisfy cooling demand is expected in the following HED model versions. Coefficient of performance is set by the user as well as its potential future improvements. This way user can calculate how future technology improvement would influence on final energy demand for space cooling.

$$Ea_i^z = Qc_i^z / COP_i^z \tag{10}$$

where: Ea_i is the final energy consumption for space cooling (PJ) and COP_i is the coefficient of performance index.

2.4. Cooking and hot water

Hot water demand is calculated roughly following the EN 15316–3-1 [21] 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. Since there are discrepancies between an individual household and the whole households sector, specific consumption is calculated based in imported data, available floor area and real final energy demand established in the base year. This is how the difference between sectoral and individual approach to the norm could be compensated.

Hot water mode calculates only energy demand based on the input data while final energy demand, based on different technologies and their efficiencies, is determined in the Fuel mix mode. Fuel mixing is described in a more detailed way in the following paragraph 2.5.

Final energy demand for cooking is calculated directly within Cooking mode, based on the same methodology used for hot water consumption. The difference in this case is that cooking demand enters Fuel mix mode as final energy demand. Because of that, Fuel mix mode is used only to determine various fuel types without calculating changes in energy efficiency. When modelling cooking demand, a combination between empirical data retrieved through polls and base year consumption was used, but just to test and verify the poll data.

2.5. Fuel mixes

HED model has a separate Fuel mix mode which combines energy efficiency of each technology and share ratio of each fuel type in the final energy demand, for every sub-category. This mode is necessary for calculating final energy demand for heating, hot water and cooking. Through this mode user can combine various technologies and fuel types in a scenario approach, in order to compare different strategies regarding future energy demand planning. Initial energy mixes are calculated based on the input data for the base year. User can set the paste of efficiency and fuel ration change for every year till the year 2050. With efficiency and fuel ratio for every technology and fuel type, final energy demand for the three previously mentioned sub-categories is calculated. Results mode is used in order to present final energy demand for electricity. In this mode electricity used for space heating, cooking and hot water is added to electricity used by electronic appliances.

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

where: F_i is the final energy demand (PJ), fd_i the energy demand (PJ), ee_i the energy efficiency index, and r_i is the share ratio of a certain fuel type index.

Presented methodology is used for calculating final energy demand for heating, hot water and cooking. Table 1 presents fuel mix used for calculating a base year fuel ratio and is shaped according to Croatian energy balance report. District heating was chosen to represent steam and hot water which are used in official

Table 1
Fuel mix used in version 1 of HED Model.

Mode	Fuel mix
Heating	Cole and Coke
	Natural gas
	Liquid fuel
	Electricity – classic
	Electricity – heat pumps
	Biomass
	District heating
Hot water	District heating
	Natural gas
	Electricity
	Solar water heating
Cooking	Natural gas
	Liquefied petroleum gas
	Electricity

Croatian energy balance when describing final energy demand of households sector. Additional fuels can be added to the model as well as additional technologies.

2.6. Hourly energy demand distribution

One of the additional features of HED model is the possibility of calculating hourly distributions of heat and cooling demand. Hourly calculation is used just for controlling the results retrieved from already presented monthly calculation. The calculation procedure is the same as one presented in paragraph 2.2.1., with the exception of temperature and solar irradiation data. In the hourly calculation these two parameters are imported into the model as hourly values. This means that every county is represented with 8760 temperature and solar irradiation values. The main intention of hourly demand projections is making HED model compatible with advanced energy system analysis tools which use hourly demand distribution as their input data [22][23]. With HED model, user can export hourly heat and cooling demand distributions for any year till 2050. Although focus of this paper is on total yearly final energy demand, hourly heat demand will be presented in the Results paragraph.

2.7. Croatian National Energy Strategy

Official projections for households sector in Croatian Energy Strategy are presented till the year 2020 with the view till 2030 [24]. HED model gives us prediction of final energy demand till 2050. In order to compare results from this paper to the Croatian Energy Strategy, basic projection of the National Energy Strategy, from 2030 till 2050 was made. This was done strictly for basic comparison with HED model results while the calculation is based on population data, GDP/capita and energy intensity, as main calculation parameters [25].

3. Results and discussion

One of the main intentions of this paper was to investigate and present the influence of future energy regulations regarding renovation and zero energy buildings. On Fig. 2 heat demand for the reference scenario is presented with the yearly renovation rate of 1% and with classifying all new buildings entering the households stock as "zero energy buildings" after the year 2021. Every building renovated after 2026 is also considered as "zero energy building". This of course means they still consume energy but that energy has to be produced locally from renewable energy source. "Zero energy buildings" as well as buildings renovated to "zero energy" standard are used to show potential energy savings and potential for the implementation of distributed renewable energy sources [26]. The year 2026 was chosen arbitrary but with the consideration on some experientially data since certain prolongation regarding refurbishment to "zero energy" standard is expected in Croatia. HED model has the possibility of choosing any year after which new or renovated buildings are built on "zero energy" standard and is left to the person using the model to decide.

This renewable energy that would need to be produced locally is presented by marked surface in Fig. 2. Referent scenario calculates specific floor area in square meters per a resident with a total increase of 20% from the year 2008 till 2050. This is done so an increase in floor area per a resident could be presented. Different scenarios with this percentage increased will be presented in the following diagrams.

Renovation rate presents an important parameter since it directly influences future heat or cooling demand. On Fig. 3 different heat demands are presented depending on the applied yearly renovation rates. This is the case if all new and renovated buildings would strictly follow current and future building codes. As can be seen from the Fig. 3 renovation rate could be a significant parameter in planning future energy demand of a households sector. In Croatian case the difference in heat demand for the year 2050 between 1% and 3% yearly renovation rate is almost 17%. When calculating thermodynamic characteristic, whether regarding heat or cooling demand, including solar gains turned out to be a significant component. It was confirmed that without consistent solar gains calculation, heat and cooling demand cannot be compared well with the official energy balance [14]. Important aspect was to test unknown variables in order to safely use them in the forecasting calculation.

Results connected to heat demand are presented because space heating, with a share of 57%, is the highest energy consumer of Croatian households sector [1]. Since HED model can calculate hourly heat and cooling demand for every year until 2050 it gives an additional opportunity to test the monthly calculation method but also gives a valuable input for future advanced energy systems analysis (Fig. 4). On Fig. 5 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 Figs. 5 and 6 presents final energy demands together with new and renovated "zero energy buildings" energy demand. Referent scenario does not include migration between Croatian counties but assumes constant share ratios, calculated in the base year. After energy used for heating, most significant sub-category is appliances which uses electricity for its operation.

This paper gives a comparison between official Croatian National Energy Strategy demand projections and the results of HED model. On Fig. 7 National demand projections are compared with the HED model reference scenario. National Energy Strategy gives forecast for households sector just for 2020 and 2030. For the purposes of this paper basic energy demand curves for National Energy Strategy have been modelled for the period 2030–2050, in accordance with the methodology presented in paragraph 2.7. Modelled period is marked with full lines in the Fig. 7. Forecasting is done through three parameters: demographic, gross domestic product and energy intensity.

Comparing national energy demand projections with HED model results leads to significant differences, as can be seen on Fig. 7. Energy savings calculated by HED model can range from 23 PJ to 45 PJ in the year 2050. If we compare two extreme scenarios which are National Energy Strategy BAU (Business as usual) and Reference scenario with 20% increase of floor area energy savings would be 45 PJ while if we compare National Energy Strategy SUSTAINABLE to Reference scenario with 40% increase of floor area energy savings

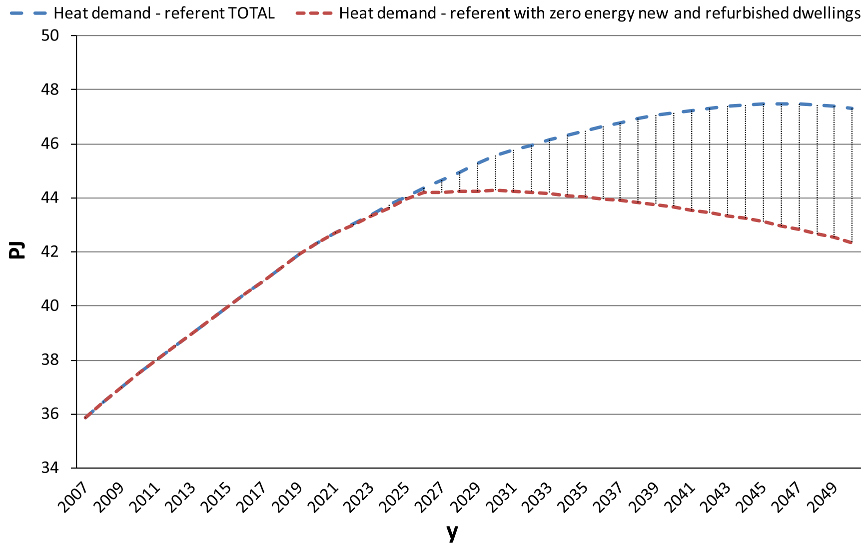

Fig. 2. Referent scenario – difference between total heat demand and heat demand including zero energy new and refurbished dwellings.

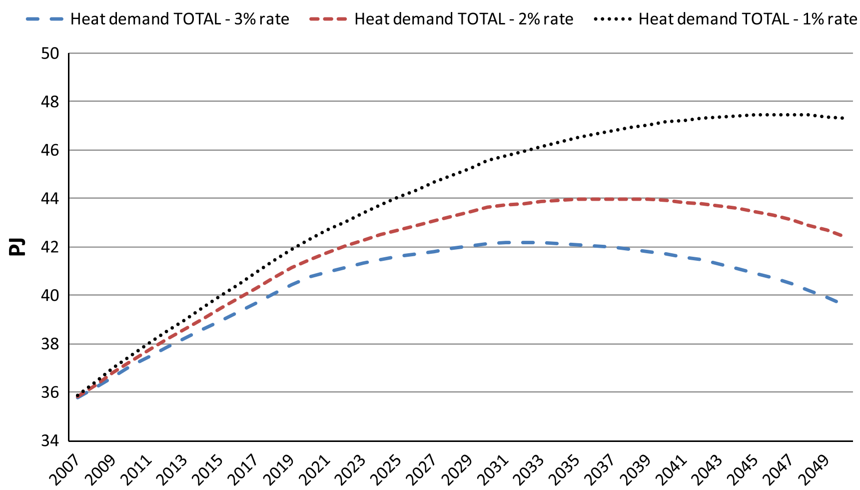

Fig. 3. Total heat demand depending on different refurbishment yearly rates until year 2050.

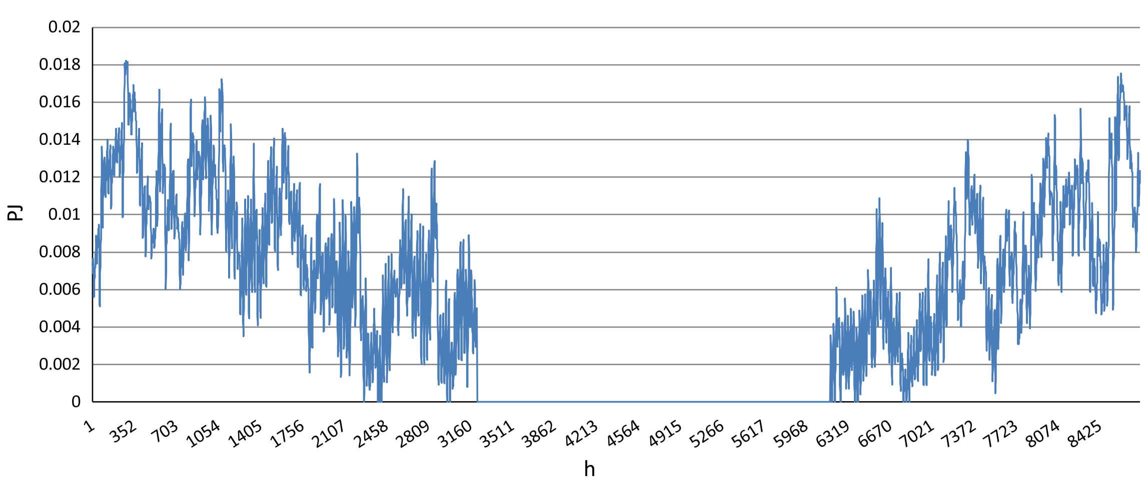

Fig. 4. Hourly heat demand distribution of a reference scenario for the year 2030.

would be 23 PJ. One of the possible reasons for this difference could lie in the methodology approach. HED model, based on its bottom up end use methodology, could give more detailed image of all trends that would be important for future energy demand.

Focus of this paper is on the energy demand projections. Fuel mixes are calculated through this model in order to have a unified and meaningful demand representation, fuel wise. Energy storage (weather regarding heat or electricity) and its dynamics would

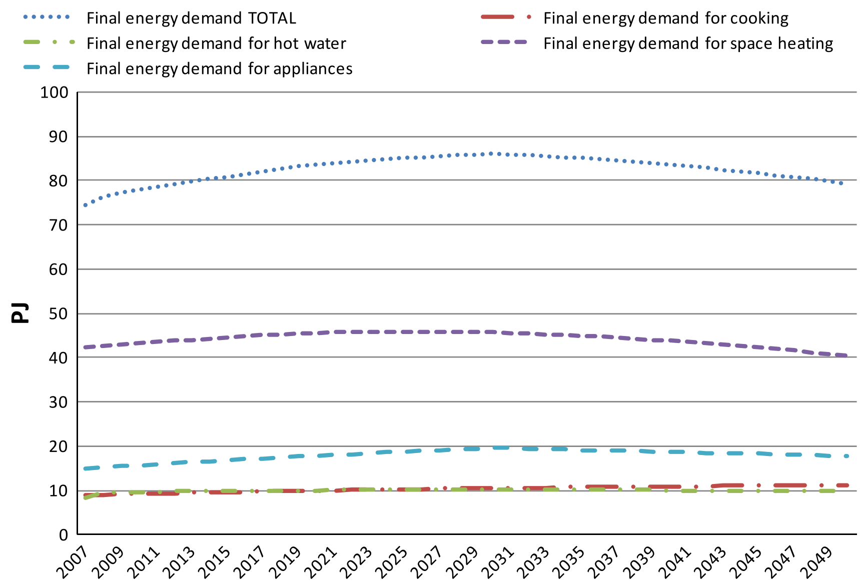

Fig. 5. Final energy demand – Reference scenario till year 2050.

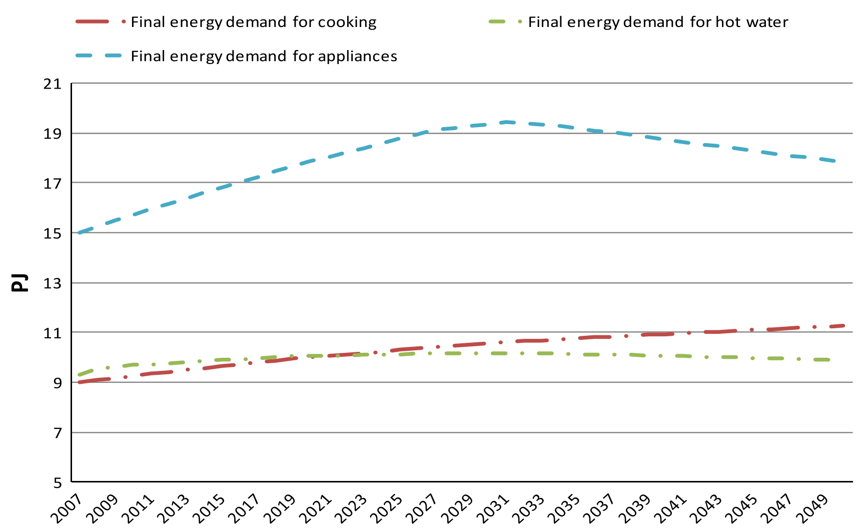

Fig. 6. Final energy demand – Reference scenario till year 2050.

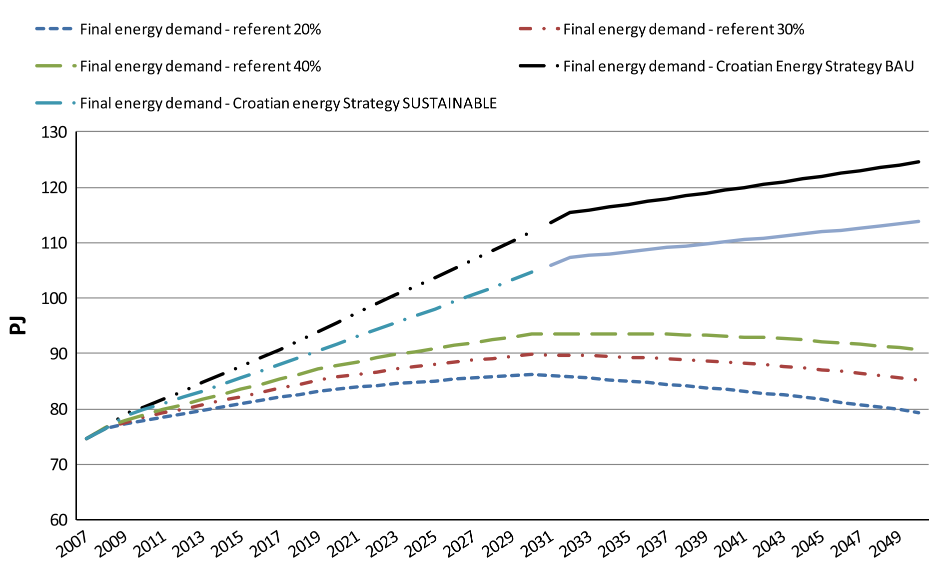

Fig. 7. Final energy demand projections comparison.

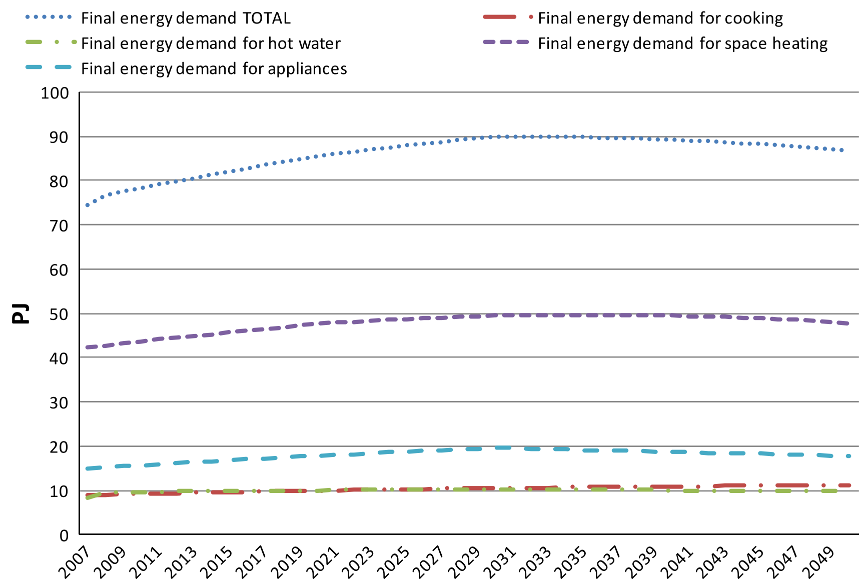

Fig. 8. Final energy demand – biomass options.

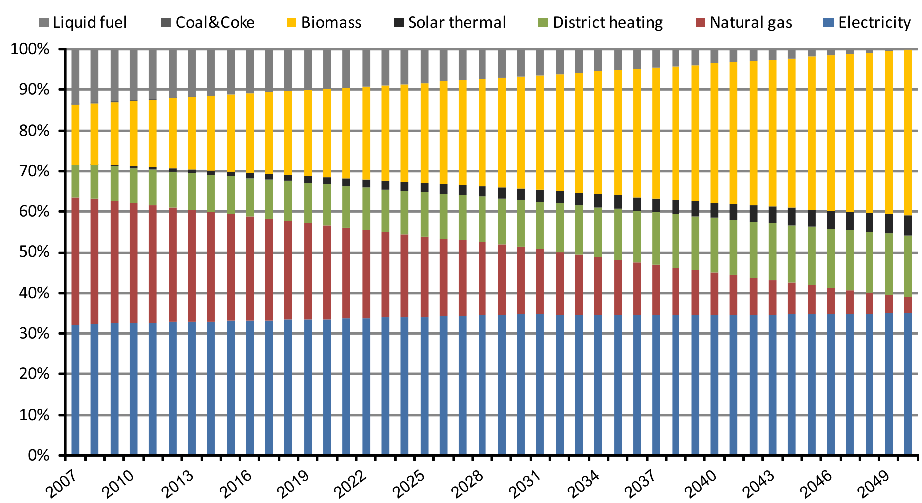

Fig. 9. Fuel share – biomass option.

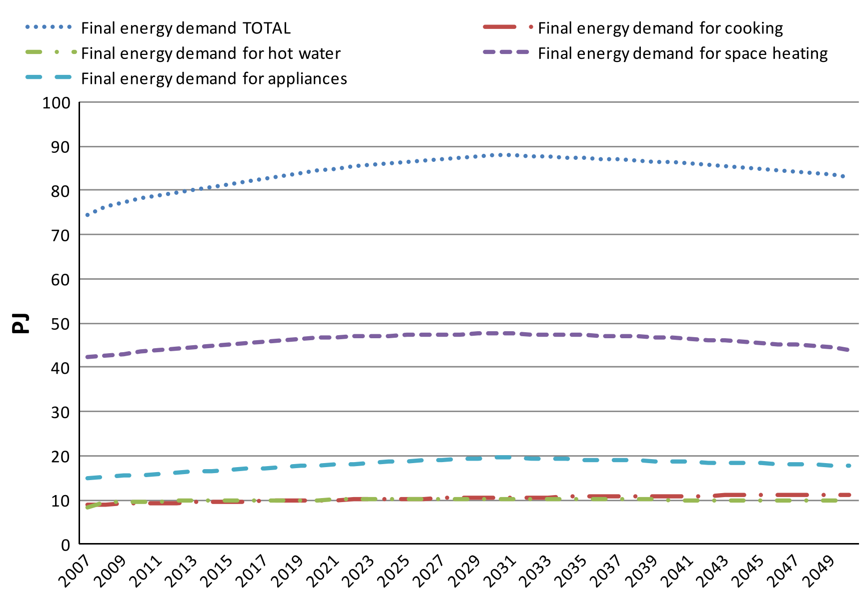

Fig. 10. Final energy demand – district heating option.

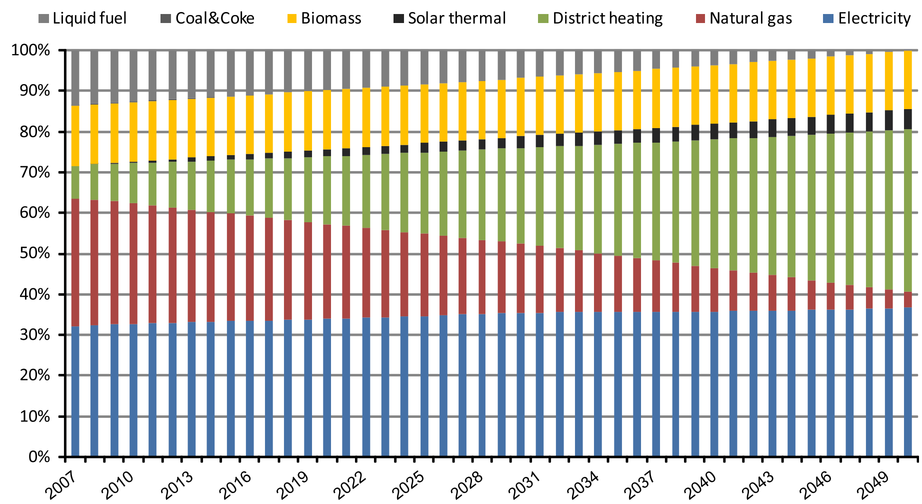

Fig. 11. Fuel share – district heating option.

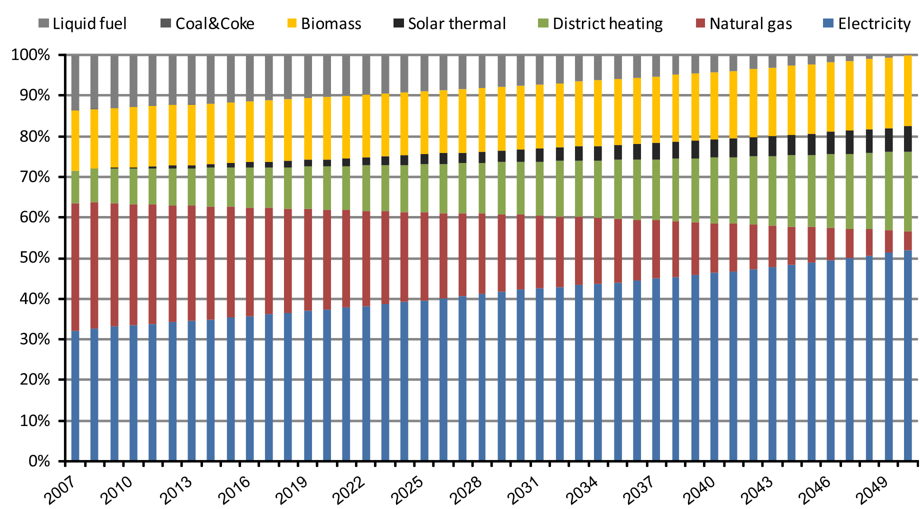

Fig. 12. Fuel share – heat pumps option.

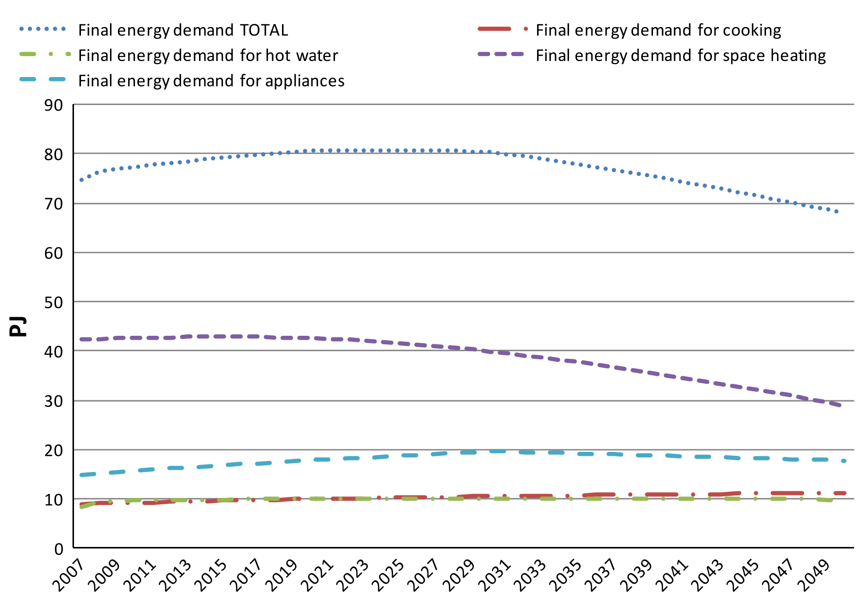

Fig. 13. Final energy demand – heat pumps option.

be very important in the final energy demand distribution, however this research would fit under the domain of advanced energy systems analysis.

It is very difficult to assess energy efficiency improvements and technology development, especially through long term energy demand model. HED model has the possibility of introducing new technologies and phasing out old ones with the decision being solely on the user. One of the examples of phasing out technologies is classic electric heating. Energy efficiency improvements are based on the similar principle. Efficiency of every technology is tested through base year where reference values are determined. Afterwards user defines energy efficiency fluctuation for every technology used in the electrical appliances mode as well as for heating and hot water.

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. 8 energy demand of biomass scenario is presented while Fig. 9 gives share ratios of different fuels of the same scenario. In this case biomass option would increase total final energy demand when comparing it to the reference scenario since in the reference scenario we had more unified distribution of technologies and fuel types. Similar situation happens with district heating option regarding final energy demand (Fig. 10), while fuel shares changes in favour for district heating (Fig. 11). HED model calculates final energy demand for district heating solely because of available data received from Croatian energy balance [1]. For all future versions of HED model, more detailed structure of district heating, primarily types of fuel used, is needed.

High penetration of heat pumps would lead to an increase of electricity consumption in the future period (see Fig. 12). However this electricity could be produced locally and from renewable energy sources. In the year 2030 heat pumps option could lower the final energy demand significantly (see Fig. 13). If compared with biomass option this savings could go up to 10 PJ with significant increase till 2050, as the renovated buildings stock becomes more expressed. Future building stock, tending to be passive or zero energy will have a hard time achieving this without heat pumps.

4. Conclusion

Croatian households sector presents a big opportunity for energy savings and penetration of renewable energy sources in the future. One of the key elements is enforcing current building codes and directives for all buildings that are being built or renovated. Applying these codes and directives strictly would lead to significant energy savings. Heat demand difference in the year 2050 between 1% refurbishment rate and 3% refurbishment rate for the whole buildings stock is almost 17%. 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. Results show that at least 15% of heat demand should be satisfied locally and from renewable energy sources in the year 2050. For this to be applicable, changes regarding zero energy buildings, both new and refurbished ones, needs to be done in the mid 2020s. For Croatian households sector, turning heavily into biomass, heat pumps and district heating seems the most logical choice for the future, with heat pumps being the most favourable because of their positive impact on lowering final energy demand. From the energy efficiency perspective there are two main tasks in achieving lower final energy demand. First one is lowering actual needs, with the implementation of different legal mechanisms, while the other one is the technology impact. This means satisfying all of the needs with the most efficient technology and fuel type. One of the conclusions drawn from the presented results is the fact that Croatian National Energy Strategy demand scenarios regarding households sector needs to be considered with a certain reserve since bottom up modelling shows room for implementing different mechanisms that ultimately have the consequence of lower final energy demand.

References

[1] Vuk B, Vukman S, Karan M, Fabek R, Zivkovic S, Maricevic M, et al. Annual energy report – Energy in Croatia. Zagreb, Croatia: Ministry of Economy, Labour and entrepreneurship; 2009.
[2] Schneider DR, Duić N, Bogdan Ž. Mapping the potential for decentralized energy generation based on renewable energy sources in the Republic of Croatia. Energy 2007;32:1731–44.
[3] Aste N, Adhikari RS, Buzzetti M. Beyond the EPBD: the low energy residential settlement Borgo Solare. Appl Energ 2010;87:629–42.
[4] Popescu D, Bienert S, Schützenhofer C, Boazu R. Impact of energy efficiency measures on the economic value of buildings. Appl Energ 2012;89:454–63.
[5] Duić N, Juretić F, Zeljko M, Bogdan Ž. Croatia energy planning and Kyoto Protocol. Energ Policy 2005;33:1003–10.
[6] Ćosić B, Markovska N, Krajačić G, Taseska V, Duić N. Environmental and economic aspects of higher RES penetration into Macedonian power system. Appl Therm Eng 2011. http://dx.doi.org/10.1016/j.applthermaleng.2011.10.042.
[7] Krajačić G, Duić D, Da Graça Carvalho M. How to achieve a 100% RES electricity supply for Portugal? Appl Energ 2011;88:508–17.
[8] Alberg Østergaard P, Vad Mathiesen B, Möller B, Lund H. A renewable energy scenario for Aalborg Municipality based on low-temperature geothermal heat, wind power and biomass. Energy 2010;35:4892–901.
[9] Krajačić G, Duić N, Zmijarević Z, Vad Mathiesen B, Anić Vučinić A, da Graca Carvalho M. Planning for a 100% independent energy system based on smart energy storage for integration of renewables and CO_2 emissions reduction. Appl Therm Eng 2011;31:2073–83.
[10] Peeters L, de Dear R, Hensen J, D'haeseleer W. Thermal comfort in residential buildings: comfort values and scales for building energy simulation. Appl Energ 2009;86:772–80.
[11] Shimoda Y, Yamaguchi Y, Okamura T, Taniguchi A, Yamaguchi Y. Prediction of greenhouse gas reduction potential in Japanese residential sector by residential energy end-use model. Appl Energ 2010;87:1944–52.
[12] Murata A, Kondou Y, Hailin M, Weisheng Z. Electricity demand in the Chinese urban household-sector. Appl Energ 2008;85:1113–25.
[13] Swan LG, Ugursal VI. Modeling of end-use energy consumption in the residential sector: a review of modeling techniques. Renew Sust Energ Rev 2009;13:1819–35.
[14] Wan KSY, Yik FHW. Representative building design and internal load patterns for modelling energy use in the residential buildings in Hong Kong. Appl Energ 2004;77:69–85.
[15] Aydinalp M, Ugursal VI, Fung AS. Modelling of the space and domestic hot-water heating energy-consumption in the residential sector using neural networks. Appl Energ 2004;79:159–78.
[16] International energy agency – World energy model, <www.iea.org/weo/model.asp> [accessed 22.02.12].
[17] Kannan R, Strachan N. Modelling the UK residential energy sector under long-term decarbonisation scenarios: comparison between energy systems and sectoral modelling approaches. Appl Energ 2009;86:416–28.
[18] Marszal AJ, Heiselberg P, Bourrelle JS, Musall E, Voss K, et al. Zero energy building – A review of definitions and calculation methodologies. Energ buildings 2011;43:971–9.
[19] Energy performance of buildings-calculation of energy use for space heating and cooling ISO 13790, 2nd ed.; 2008. <www.iso.org/iso/catalogue_detail.htm?csnumber=41974> [accessed 12.02.12].
[20] Energy efficiency indicators in Europe – ODYSSEE-MURE; 2010. <www.odyssee-indicators.org> [accessed 15.04.11].
[21] Heating systems in buildings – Method for calculation of system energy requirements and system efficiencies – Part 3–1: Domestic hot water systems, characterisation of needs – DIN EN 15316–3-1. Berlin, Germany; 2008.
[22] Segurado R, Krajačić G, Duić D, Alves L. Increasing the penetration of renewable energy resources in S. Vincente, Cape Verde. Appl Energ 2011;88:466–72.
[23] Connolly D, Lund H, Mathiesen BV, Leahy M. The first step towards a 100% renewable energy-system for Ireland. Appl Energ 2011;88:502–7.
[24] Adaptation and upgrade of Croatian Energy strategy – Green book. Zagreb, Croatia: Ministry of Economy, Labour and entrepreneurship; 2008.
[25] Graus W, Harmelink M. Global low energy demand scenarios 2003-2050. Utrecht, The Netherlands: Ecofys BV; 2008.
[26] Lund H, Marszal AJ, Heiselberg P. Zero energy buildings and mismatch compensation factors. Energ buildings 2011;43:1646–54.
[27] Državni zavod za statistiku (Croatian Bureau of Statistics). <www.dzs.hr> [accessed 12.02.12].