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ENERGY LOAD FORECASTING MODEL FOR INTEGRATED URBAN ENERGY PLANNING

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Abstract. Nearly 75 % of the world's energy is consumed in urban areas and it is expected that together with the cities expansion it will grow rapidly in the future. Therefore the energy management in the urban areas is crucial in the context of depleting fossil fuels, climate change, energy supply security and energy poverty. Energy load forecasting is essential for the sustainable energy supply management.

Planning of the energy systems starts at the stage of urban spatial planning when only limited data are available, most often those are only restrictions on building density and nature of possible land use. Existing practise of energy demand evaluation at the stage of urban spatial planning lacks integration of different energy forms and different evaluation approaches. Currently applied methodologies demonstrate significant approach differences when evaluating electricity and heat loads. The practise to calculate only peak and annual demand is insufficient. They should be expanded and incorporate seasonal or even hourly energy load profiles.

The model has been developed to address the needs for integrated energy load forecasting at urban scale. This model is designed to forecast urban scale heat, electricity and natural gas load in residential building areas. Following the analysis of different existing energy forecasting methods, end-use energy load forecasting approach was incorporated into the model. Created model is based on Lithuanian conditions, but it can be easily adjusted to other conditions as well. The paper describes the model and possibilities of further improvement of integrated urban energy planning.

Keywords: energy load forecasting, energy planning, electricity load, heat load, urban planning, heat supply, integrated planning.

1. Introduction

Half of the world's population lives in cities and nearly 75 % of the global energy consumption is used in urban areas. It is expected that together with the cities expansion urban energy consumption will grow rapidly in the future (The World Bank 2009). Therefore a sustainable energy planning at urban scale gains an increasing and pending attention.

The starting point for energy supply planning is predicting an energy load. As alternative energy sources broadly replace conventional, an energy load forecasting becomes even more sophisticated task as it is not enough to estimate energy design loads and annual demands already, but detailed energy load profiles and their integration are required.

Several methods have been proposed to assess specific energy consumption of the existing building stocks. Some of them employ statistical bottom-up approach using census data (Fracastoro & Serraino 2010) or monitored heat consumption data of DH systems (Popescu & Asachi 2007; Şerban & Popescu 2008), electricity consumption data from power utility companies (Widén et al. 2007; Pedersen et al. 2008). Additional data became available with the spread of automated reading meters (Wallin et al. 2009).

The simultaneous assessment of heat and electricity loads is necessary when designing CHP (Huamani & Orlando 2007) and energy storage systems. The importance of integrated planning of systems with different energy carriers was noticed also when planning energy at urban scale (Geidl & Andersson 2007; Hashimoto et al. 2007). Planning of systems with different energy carriers requires application of harmonized prediction methods for different energy forms.

Besides the integration of power, heat and natural gas systems in the energy planning, urban planners highlight the need for higher degree of integration between both land and energy planning. The coherent land and energy planning approach is one of the main principles of sustainable city planning.

Energy load forecasting models can be divided into statistical, energy modelling and intelligent computer systems. Hybrid models that use statistical data together with elements of energy modelling are also common (Pedersen 2007).

Statistical models are the most suitable for the steady state situations, were no major changes are foreseen. In this case the planned territory almost fully corresponds to the existing one from which the data is obtained. Another way is to collect statistical data of existing typical buildings and to perform a forecasting by incorporating this data into the spatial build-up structure of the newly planned territory. Statistical methods are rather simple but the statistical data cannot be directly applied when conditions are expected to be different. There are certain variables that have to be evaluated: climatic data, the structure of energy users and their behaviour, constantly tightening requirements for energy efficiency and etc. On the other hand, if the data are taken from the more developed country that is close culturally compared to the country where the planning is taking part, there is a possibility that in the future the behaviour of the energy end users in the planned country will undergo similar change. Due to this fact the actual statistical data of more developed countries (the part that is determined by the end users behaviour) can ideally fit to the future prognosis of less developed ones.

The modeling methods are much more time consuming than the direct application of the statistical data. Additionally the precise results are received only if input data are correct. Thus energy modelling is common when evaluating individual buildings but is rarely used to predict energy consumption in building groups. From the common experience it is known that there are some factors that cannot be fully determined especially if it is related to the energy end users behaviour.

2. Organisational analysis of energy planning at urban scale

The organisational structure of the urban planning in Lithuania was investigated in order to expose shortcomings of the existing planning process and to construct a model allowing to overcome them.

By preparing spatial planning documents municipalities put into action their responsibility for the planning of urban land use and energy infrastructure. The function of urban land use planning is to prepare and control the use of land within a municipality for buildings or for other purposes. Heat generation and supply planning is very important function of the municipality. Municipality is also responsible for electricity supply and distribution, and in near future, as distributed generation is spreading, it will have stronger role in electricity generation planning as well.

The spatial planning could be divided into three levels: general planning, special planning and detailed planning. Energy planning is integrated into each of these levels. For example, in Lithuania the first level corresponds to general spatial plans. The main aim of the general planning is to define land use. Energy planning at this level is limited to preliminary energy infrastructure planning in order to reserve land for the infrastructure needs. In the second level energy planning corresponds to heat supply plans, natural gas infrastructure plans, power supply infrastructure plans. The detailed planning is intended to plan at the level of separate land parcels. Figure 1 shows all three levels of energy planning. The two levels that are depicted by dashed line in the figure, corresponds to urban scale planning.

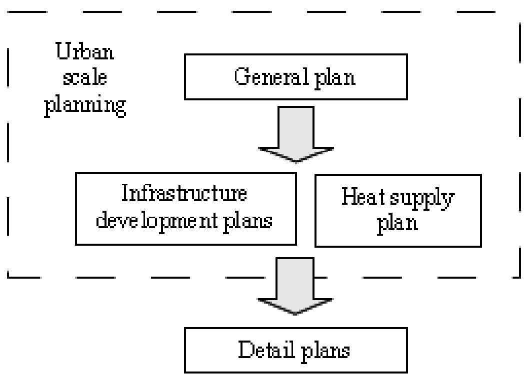

Fig 1. Scheme of the organisational structure of local energy planning

The land use planning has a high and direct impact on energy planning. The process of energy planning starts from the energy demand forecast and it is strongly related with the intended land use. Land use planning allows predicting energy demand in both, spatial and time dimensions. At the moment time dimension in land use planning is not sufficient for energy planning purposes. General plans in Lithuania provide indicators that are designed to restrict land use in terms of maximum built-up intensity and land use purposes. This results in evaluation of the maximum possible energy demands (usually with tangible reserve assurance) and designing of corresponding energy infrastructure that would be capable to supply planned amounts of energy.

In the first planning level there is a need to reserve land for infrastructure developments. This is performed by making reservation of territories for the infrastructure objects and forcing restrictions of land use due to the sanitary zones near energy infrastructure objects like heat plant, gas distribution station, power transformation stations, etc. In order to establish the aforementioned reservations and land use restrictions the number of the main infrastructure objects and their capacities are required. For this purpose the forecasting of design energy loads are made based on the maximum urban intensity for each planned territory that urban planners provide in general plans.

In the second level of the energy planning urban use data from the general plans is applied to predict energy loads in the newly planned territories. Nowadays in practise there is not enough urban data for the second level of energy planning. There would be a great waste of resources to plan the energy infrastructure for the maximal loads that could be estimated based on the maximal urban intensity allowed. The shortcoming of this approach is that this maximal urban intensity is reached only at the end of the planning period or is not reached at all. For example, general plans in Lithuania look at ten years in detail and at 20 years for conceptual planning. Some of the developments are planned at the nearest future, some – after five or ten years. That causes that energy infrastructure would be with excess capacity that will finally form a sink costs for the system operation effectiveness. Thus introduction of detailed time dimension in planning is essential. It is also important that build-up of the areas distributes in time would have a simple update procedure.

From here we can observe that there are two separate procedures that have to be kept along the planning: urban planners are able to make predictions on urban development timing, as the energy planers should supply and constantly update energy technological and economical assumptions.

The second level of energy planning also requires more elaborated investigation of energy loads. The integrated development of different energy systems infrastructure is essential at this level. Despite that the practise is to plan each type of infrastructure separately.

Analysis of energy planning organisational scheme shows the need of energy load forecast method that fulfils these requirements:

- is integrated in terms of energy infrastructure of different kind and land use;
- is simple to use by energy planners at local level;
- is adjustable (can be easily revised as more accurate data are obtained).

Creating a sustainable, integrated planning process everyone has to bear in mind that in this process all major energy infrastructures should be involved. This requires very complex coordination both in compounding necessary competences and applying organisational setup. This paper presents energy load forecasting model that is meant to simplify and integrate planning process of new urban unit.

3. General description of the energy load forecasting (ELF) model

This paper presents energy load forecasting (ELF) model that allows evaluating energy needs of planned urban unit in integrated manner. Scheme of the ELF model is shown in Figure 2.

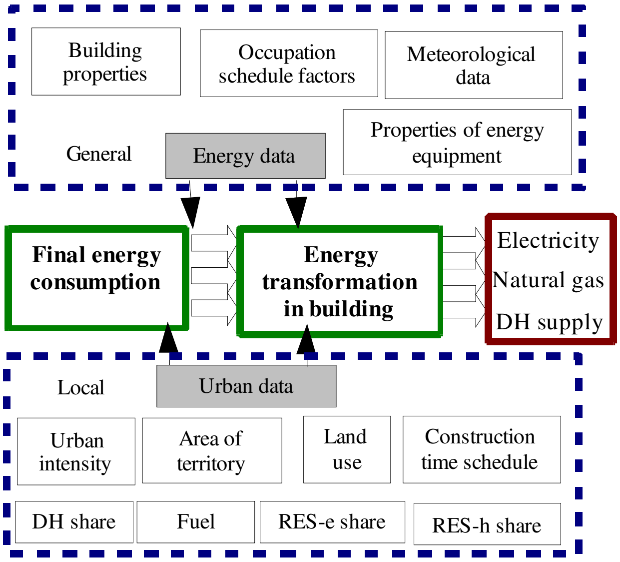

Fig 2. Schematic structure of the ELF model

ELF model consists of the input data (two blocks depicted by the blue dashed line), the modelling part (the two green blocks) and the output data (depicted by red continuous line).

The model has two blocks of input data: energy data and urban data. The idea of the chosen structure of input data is to divide the actual energy planning and the preparation of the energy assumptions. First one is left to the urban planners but the construction of assumptions should be delegated to the field experts both on the state and local levels. The division into these blocks of input data also allows to adjust forecasts when the input data changes. Model can be adjusted at two levels: at central level it can be updated if there are changes in building regulations different that were predicted; at local level urban data can be revised as data on construction schedule or urban intensities become more accurate.

The modelling part of the ELF model is divided in two blocks. Final energy demand is evaluated at the first step. It includes heat demand for space heating, ventilation and hot water preparation, electricity demand for lighting and appliances. Then energy transformation in buildings is considered. The reason of this division is to provide intermediate results to urban planners that allow making more informed decisions related to energy transformation in buildings. The example of such decisions could be share of buildings that are intended to connect to district heating (DH) network.

Output of the model is forecast of energy peak loads and annual energy demand. Forecasting of energy load profiles on hourly basis is left for the further development of the ELF model. Each load is divided into three forms of energy carrier: electricity, heat and natural gas.

Input data are described in more detail in following sections of the paper.

4. Urban input data

Urban input data that influence forecast of energy service demand is building type and area in planned territory. All planned territory should be divided into areas that are consistent unbroken in terms of urban indicators such as land use (type of buildings) and urban intensity (or building height and density). Then for each area fore mentioned urban indicators should be specified.

Urban planners usually establish maximum permissible building intensity, but urbanisation of territories extends during some years and maximum permissible intensity is rarely reached at all. To predict energy demand evolution in all planned period it is necessary to have prognosis of construction in different territories as a function of time (in years). Construction time has impact not only on the occurrence of additional energy load but also on characteristics of this load. For example, buildings constructed after ten years from now will have better thermal characteristics and different electrical systems. Thus in order to ensure sufficient accuracy urban intensity should be presented in form of construction time schedule.

Possibilities of land use are defined in the general plans. If it is possible to predict building type more exactly, more reliable results of energy load will be received. It could be indicated what percentage of each planned parcel will take one type of residential building stock: single family house, cottage, low rise multi apartment buildings, high rise multi apartment buildings.

The next group of urban input data are assumptions about energy transformation in buildings. The decision what part of buildings will be heated by DH, what are fuel restrictions, what RES goals are in heating and electricity sectors of the municipality are the responsibility of municipalities and they are reflected in the strategic documents.

5. Energy input data

ELF model considers electricity demand for lighting, appliances, heat demand for space heating, ventilation and hot water services. Energy demand for food preparation on stoves is not included into the model as it comprises rather small part of overall energy consumption. Space heating requirements include energy needs to compensate heat losses through building envelopes and due uncontrolled air infiltration. Heat requirement for fresh air provision is calculated separately as heat demand for ventilation. As only residential areas are considered at the moment, energy demand for air cooling is not included into evaluation, but with rising demand for comfort it can be an issue in coming years.

Model can be created to evaluate all types of urban land-use type but at first we simplify the task to residential building areas.

While forecasting energy load is important to look at the input parameters as variables that depend on different factors. Such insight allows to correct factors that are likely to change in the future. It also allows to look what parameters and how could be adopted at different place than they were estimated. We divide input parameters into four groups as it is shown in Table 1.

Table 1. Energy input parameters dependence

Are ingrained in construction stage (building properties)	specific heat losses, possibility to regulate indoor air temperature and ventilation, use of natural light
Depends on weather or season	outdoor air temperature, temperature of cold water, natural light
Depends on consumer purchase behaviour	efficiency of lighting bulbs, COP of boiler
Depends on curtailment consumer behaviour	indoor air temperature, ventilation rate, hot water consumption rate

The input parameters that depend from building properties, also depend on construction time (as different requirements could be in place at different years) and on type of building.

Input parameters that depend on consumer behaviour also depend on type of building (differences of people living in individual houses and multi flat buildings). The attempt to structure consumer behaviour is assuming different control strategies for HVAC systems (indoor air temperature, ventilation rate, hot water consumption rate) and usage patterns for hot water, lighting and appliance usage.

The assumptions about properties of energy equipment in buildings aim to integrate into ELF model information about efficiency and kind of energy transformation in buildings: coefficient of performance of boilers or other equipment of energy transformation in a building.

Urban and energy data are used to generate energy load profiles. The considerations about the methods that could be used in ELF model are presented further.

6. Energy load modelling

Energy load modelling at urban scale and in building has some significant differences. Input data in case of an urban scale is less accurate and thus the modelling procedure should be adequately simpler. There is also no use to introduce factors which influence the results less than an uncertainty of assumptions that are inevitable greater at the urban scale.

Even when sufficient data about each type of buildings in the modelled building stock are available for explicit energy modelling, the accuracy is diminished by an issue of aggregation. Every building has its own energy use time routine and energy use peaks of several buildings do not match. Consequently the peak energy demand of a group of buildings is less than the sum of peak energy demand of the buildings. Coincidence factor is the relation between the peak energy demand of group of buildings and sum of the peak energy demand of each building. The common approach is to use statistically established coincidence factors to calculate peak energy demand at urban scale. But there are no established procedure how to evaluate the influence of the coincidence when considering energy load profiles.

Coincidence of energy consumption could be evaluated in two ways. One way is measuring energy use of the building group and of each building in this group simultaneously. Then statistical methods could be employed to get average meanings of coincidence factor for particular types of building groups. This method has a shortcoming that obtained values will not be reliable to apply for long term energy forecasting – energy related behaviour is changing.

Another technique of energy load aggregation is to simulate energy use profiles considering different time schedules of each building energy use and then to sum them up. Some researches applied this approach and also included random number generator to simulate the nature of the behavioural factors (Yao & Steemers 2005).

We propose to use combined approach for the ELF model. Available statistical data should be used, but corrections should be made were appropriate using energy modelling approach.

In order to find what statistical data and what modelling should be employed in the model, further we analyze how different factors influence energy load.

The scheme of the relationships among energy load and different factors is presented in Figure 3.

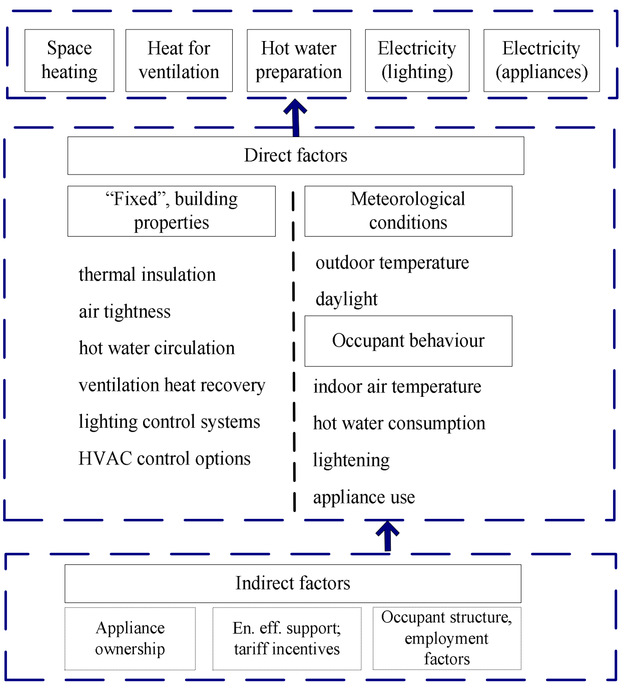

Fig 3. The scheme of the relationships among energy load and different factors

We distinguish "fixed" and "variable" factors in order to form a structure of the ELF model. Outdoor air temperature goes as separate data block. Daylight data and behavioural factors are transformed into time schedules of indoor air temperature, hot water consumption, lighting and use of appliances.

We propose that it is possible to adopt research results from other European countries to form time schedules, but to use modelling to include factors that are specific to Lithuanian conditions: properties of buildings, weather data, etc.

Further analysis is needed in order to investigate what methods to generate each energy load are proposed by other researches and how it could be applied at Lithuanian conditions. This investigation is out of scope of this paper.

Next section of the paper demonstrates example of the model application in the case.

7. Example of model application

Case analysis is presented to investigate the significance of presented approach to consider construction time in different areas. The fictitious planning area in Lithuania is used for the purpose of this analysis. It consists from 2 ha single family houses territory and 1 ha of apartment blocks territory. Planning period is 20 years, 80 % of maximum urban intensity in the area of single family buildings and 100 % of maximum urban intensity in the area of apartment blocks are reached by the end of the planning period. Maximum urban intensity are correspondingly 0,4 and 1,2. Two different scenarios of urbanisation timing are investigated. The major part of buildings are constructed in the first 5 years of planning period in the I scenario, and the major part of buildings are constructed in the last 5 years of planning period in the II scenario. The whole construction time schedule in two scenarios is shown in Table 2.

Table 2. Construction time schedule expressed as part of buildings that are constructed during particular year

	Planning year	1	2	3	4	5	6	7	8	9	10	11
I scenario	single family houses	5	5	10	30	10	10	5	5	0	0	0
	of apartment blocks	0	0	0	50	50	0	0	0	0	0	0
II scenario	single family houses	0	0	0	0	0	0	0	0	0	0	0
	of apartment blocks	0	0	0	0	0	0	0	0	0	0	0

	Planning year	12	13	14	15	16	17	18	19	20
I scenario	single family houses	0	0	0	0	0	0	0	0	0
	of apartment blocks	0	0	0	0	0	0	0	0	0
II scenario	single family houses	0	0	5	10	10	30	10	10	5
	of apartment blocks	0	0	0	0	0	50	50	0	0

Assumptions that have been made in energy part are: envelope insulation, air tightness and ventilation heat recovery requirements will be straightened each 5 years and that will condition decrease of heat demand requirement in buildings that are built in corresponding years by 10 %. Hot water consumption will remain constant. Electricity consumption will increase by 2 % annually and this increase will not depend on the year of building construction.

Heat load forecast is presented in Figure 4.

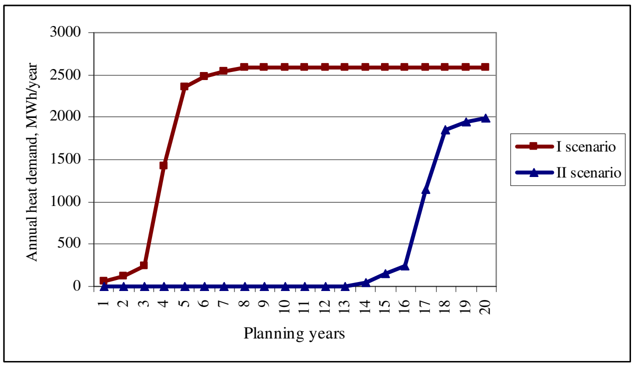

Fig 4. Allocation of heat loads during planning period

Electricity load forecast is presented in Figure 5.

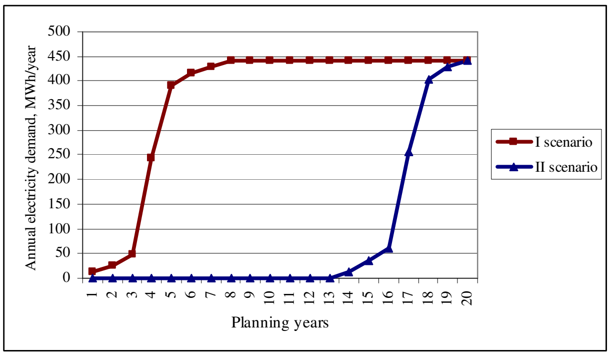

Fig 5. Allocation of electricity loads during planning period

As it could be seen from Figure 4, heat load could vary significantly when the same urban intensity is reached but the construction of buildings distributes differently during the planning period. The discrepancy in the case analysed is 23 %.

As electricity load does not depend on the construction time of buildings, electricity load is the same at the end of the planning period in both scenarios. But as demonstrated in Figure 5, electricity, as well as heat, load distribution in time differs significantly. Not paying attention to this could result in inefficient planning of urban energy supply infrastructure and generators. Thus the ELF model that evaluates the construction timing helps to integrate land use and energy planning and thus to avoid costly mistakes.

8. Conclusions

1. This paper presents investigation and review of sustainable urban energy planning. Problems indicated in Lithuanian legal and practical planning base comparatively close corresponds to the reviewed researchers' findings abroad. Despite generally approved deficit for sustainable, integrated planning measures there are only pre-assumptions for the ones.
2. This paper presents model of energy load forecasting for integrated energy planning that is identified as a core starting topic for the whole adequate planning process.
3. Integrated and sustainable approach is implemented in the ELF model by sustaining these principles:
   - analyze all three common energy carriers (electricity, district heat, natural gas) together;
   - see an energy planning in the context in the land use planning;
   - evaluate the outcomes of land use planning to energy use in the early land use planning stage.
4. The unique features of the ELF model are as follows: model is intended to produce energy prognoses in form of aggregated electricity, heat and natural gas hourly and annual load profiles for planned urban territories simultaneously; in order to simplify the use of the model and encourage to integrate energy and land use planning input data are divided in two blocks: urban indicators and energy data.
5. ELF model input data division is made due to the existing necessity in dividing experts' responsibilities and base them on their field of expertise. Urban planners should have up to date energy forecasts that are constructed by energy economy specialists. These assumptions should be constantly updated. Due to that planning process is adaptive and could more easier be adjusted in relation to the unforeseen or changing factors.
6. ELF model could serve to a number of purposes. Design energy load estimations with the time of their emerging allow planning urban energy supply infrastructure with more preciseness. Energy load profiles gives opportunity to look for more sophisticated sustainable energy supply and generation solutions. ELF model could be also used to model the impact of energy efficiency and RES support incentives at the national or local level. Model could also provide insight how to reduce energy demand peaks by introducing various incentives to change occupant behaviour.
7. ELF model at the moment provides peak load and annual energy demand forecast for common energy carriers. But it requires further improvements in energy load modelling method in order to generate hourly energy profiles. There is also a lack of input data that could ensure hourly energy forecasting at urban scale in Lithuania.

References

Fracastoro, G.V. & Serraino, M.; 2010. A methodology for assessing the energy performance of large scale building stocks and possible applications. *Energy and Buildings*. Available at: http://linkinghub.elsevier.com/retrieve/pii/S037877881000424X [Accessed January 12, 2011].

Geidl, M. & Andersson, G.; 2007. Optimal Coupling of Energy Infrastructures. *2007 IEEE Lausanne Power Tech*, pp.1398-1403. Available at: http://ieeexplore.ieee.org/lpdocs/epic03/wrapper.htm?arnumber=4538520.

Hashimoto, S. et al.; 2007. Simulation Model for Multi-Purpose Evaluation of Urban Energy System. In *Proceedings: Building Simulation 2007*. pp. 554-561.

Huamani, M. & Orlando, a, 2007. Methodology for generating thermal and electric load profiles for designing a cogeneration system. *Energy and Buildings*, 39(9), pp.1003-1010. Available at: http://linkinghub.elsevier.com/retrieve/pii/S0378778806002763 [Accessed January 5, 2011].

Pedersen, L.; 2007. *Load Modelling of Buildings in Mixed Energy Distribution Systems*.

Pedersen, L.; Stang, J. & Ulseth, R.; 2008. Load prediction method for heat and electricity demand in buildings for the purpose of planning for mixed energy distribution systems. *Energy and Buildings*, 40(7), pp.1124-1134. Available at:
http://linkinghub.elsevier.com/retrieve/pii/S0378778807002381 [Accessed September 11, 2010].

Popescu, D. & Asachi, G.; 2007. Simulation of space heat demand. In *6th international conference on electromechanical and power systems*. Chisinau, Rep.Moldova, pp. 243-246.

The World Bank, 2009. *Energy Efficient Cities: Assessment Tools and Benchmarking Practices* R. K. Bose, ed.;

Wallin, F. et al.; 2009. Automatic Meter Reading Provides Opportunities for New Prognosis and Simulation Methods. , (July 2006), pp.1-6.

Widén, J.; Wäckelgård, E. & Ellegård, K.; 2007. Modeling Household Electricity Load From Time-Use Data. , pp.1-9.

Yao, R. & Steemers, K.; 2005. A method of formulating energy load profile for domestic buildings in the UK. *Energy and Buildings*, 37(6), pp.663-671. Available at: http://linkinghub.elsevier.com/retrieve/pii/S037877880400307X [Accessed July 13, 2010].

Şerban, E. & Popescu, D.; 2008. Prediction of Domestic Warm-Water Consumption. *WSEAS Transactions on Computers*, 7(12), pp.2032-2041.

Ministry of Economy, 2007. Methods of design electrical load assessment, p.14 (in Lithuanian).