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A spatial model of interaction between land-use planning and urban climate

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1. Abstract

Global warming is changing the urban climate and influencing human society. A report from Royal Netherlands Meteorological Institute (KNMI, 2013), showed that the temperature will rise globally by 1,0 -2,3°C in 2050 and 1,3-3,7°C in 2085. To strategically deal with this issue, this project aims at planning the future city to adapt changing climate. Furthermore, there are four scenarios (G_L, G_H, W_L, and W_H) are used as a reference to investigate the relation of land use planning and urban climate (KNMI, 2014), which are based on global airflow and temperature changes. To extend this issue, this research identifies the role of the urban climate to urban planning. Analysis of variance indicates statistical effects of different categories of land-use type to neighboring areas, these effects reflect on temperature difference to the central area with the study region. The impact ratio to temperature in central area is thoroughly researched in different neighboring land-use types and distance. In this research, the geospatial database has linked the urban database with the urban climate model. For this study, Rotterdam is used as a case study because it is a delta city, and more than half of the habitants are vulnerable to climate change (City of Rotterdam, 2013). The selected area in the city of Rotterdam, the Netherlands is used as a case study. Finally, a spatial model of interaction between land-use planning and urban climate is presented, which provides a hypothetical guideline for sustainable city.
Keywords: urban planning, energy consumption, urban climate, land use, zoning

2. Introduction

Climate Change (IPCC), has stated that that approximately 20-30% of species assessed so far are likely to be at increased risk of extinction if global average warming exceed 1.5-2.5 °C (relative to 1980-1999). As global average temperature increase exceeds about 3.5 °C, model projections suggest significant extinctions (40-70% of species assessed) around the globe. Netherlands is also one of the countries which is under the threat of global warming. Between 1901 and 2013, the average temperature in De Bilt, the Netherlands has increased by 1.8 ° C. The major increase took place between 1951 and 2013 (1.4 ° C). Since 1951, the increase is about twice as large as the global increase in average temperature over land and sea surface. In general, the land warms faster than the ocean. The winter (December, January and February) were softer because the wind came more from the west. Summers (June, July and August) were extra warm by an increase in solar radiation, mainly due to the decreased air pollution.

The aim of this paper is reviewing the past research articles which can help to build up a L-E-T spatial model to investigate the correlationship of land use/ land cover (L), energy (E), and urban climate (T). These papers provide the overview while designing the L-E-T spatial model, no matter on optimal temporal/ spatial scale, various kind of urban models, and spatial indicators. This L-E-T spatial model will provide the urban planners and policy makers a forecast for the future city through the observation data of urban temperature trend in KMNI (climate scenario and changes).

In the first section of this paper the land use/ land-cover change models are investigated by searching a variety of journals and policy papers. Key words used for searching are “land use”, “energy”, “temperature”, “land”, “land cover”, “urban energy”, “UHI”, “urban planning”, and “model.” In Europe, buildings account for 40% of total energy use and 36% of total CO_2 emission[1]. Hence, this L-E-T spatial model will focus on the built environment. The previous researches have been done in different scales of urban modeling which focus on correlationship of L-T, L-E, and E-T. The methods used to investigate these relationships are stated in the following paragraphs. There are three main kinds of paper types: (1) papers which focus on the spatial dimension; (2) policy articles which focus on temporal simulations; (3) analytical models which have specific areas as focus points.

3. Methodology

3.1 Spatial dimension

Based on the review papers related to urban climate and energy demand, GIS is one of the most common tools for dealing with spatial data in recent decades. Table. 1 shows the L-E-T co-relationship research in the reviewed papers.

Table. 1 The L-E-T correlationship research with focus on spatial dimension

Citation	Research Method	L	E	T
Lisa White and Bram F. Noble (2013)[2]	SEA (strategic environmental assessment)	Land use	Sustainable energy	
Saleh Mohammandi et al. (2013)[3]	Use top-down, bottom-up approach and spatial evaluation for energy demand and supply model. Compare the Integrated modeling approach using source flow in neighborhood	Land use, land cover, building type	Energy supply (solar thermal energy, solar radiation, natural light), energy demand (energy price), energy integrated model (energy performance)	
Jorge Gil and Jose´ Pinto Duarte (2013)[4]	Analytical framework covering the format, structure, content and output of the tools	Sustainable urban development (land use, density, mobility infrastructure, street layout and building type),Land use evolution and impact assessment model (LEAM), Sustainable urban landscapes (SUL)	Building energy measurement and rating systems, energy consumption, energy use levels, energy or transport, leadership in energy and environmental design neighborhood development (Leed-ND), building energy assessment tools	
Hai-xiang Zhao and Frédéric Magoulès (2012) [5]	The prediction methods: engineering methods, statistical methods, neural network, support vector machines, grey models	Building types: office, residential and engineering buildings. Scale varying from small rooms to big estates	Monthly energy consumption, daily energy consumption, annual energy consumption, electric energy consumption, hot-water heating energy consumption, predict energy consumption. Evaluating energy efficiency, renewable energy, and sustainability in buildings, such as DOE-2, EnergyPlus, BLAST, ESP-r	Indoor/outdoor air temperature, dry-bulb temperature, temperature frequency method, monthly temperature, daily temperature, maximum and minimum temperatures, water temperature
C.S.B. Grimmond et al. (2010)[6]	Identify modeling approaches that minimize the errors in the simulated fluxes of the urban energy balance and to determine the degree of model complexity required for accurate simulations	Land-surface Parameterization Schemes, Community LandModel-Urban (CLUM), Noah land surface model (NSLUCM)	Urban surface energy, energy storage within the buildings, the road and underlying soil, sources of energy, BEP coupled with Building Energy Model, Slab Urban Energy Balance Model (SUEB), Simple Urban Energy Balance Model for Mesoscale Simulation Town (SUMM), Town energy balance (TEB), energy exchanges per facet, energy budget	Within-canyon air temperatures, facet surface temperature, temperature of Urban Facets 2D (TUF2D), Temperature of Urban Facets 3D (TUF3D), minimum /maximum temperature, internal building temperature, surface temperature, mean internal building temperature (K), deep temperature (K), facet temperature (K), min/max internal building temperature (K)
Diana E. Bowler et al. (2010)[7]	Use systematic review methodology to evaluate available evidence on whether greening interventions, such as tree planting or the creation of parks or green roofs, affect the air temperature of an urban area	Green area types: green roof, grass, tree, forest, park	Surface energy balance, radiation consume energy	Urban temperature, air temperature, land surface temperature, one day temperature difference (green roof, grass, tree, forest, park), daily temperature, ground temperature
Lukas G. Swan, V. Ismet Ugursal (2009)[8]	Two distinct approaches are identified: top-down and bottom-up. The top-down approach treats the residential sector as an energy sink and is not concerned with individual end-uses. The bottom-up approach extrapolates the estimated energy consumption of a representative set of individual houses to regional and national levels, and consists of two distinct methodologies: the statistical method and the engineering method	Residential sector	End-use energy consumption, residential energy model, residential energy consumption, housing energy model, actual energy billing, international values of unit energy consumption (UEC), calculating energy consumption (building type, energy standards, efficiency, and heat demand per area), power ratings and use characteristics and/or heat transfer and thermodynamic principles, energy consumption appliances (commonly appliances, refrigerator, hot water, space heating and cooling), monthly energy consumption, resultant energy consumption, variables for energy consumption (number of occupants, electricity price, household income, floor area, heating/ cooling per unit area)	
Luis Pe ´rez-Lombard et al. (2008)[9]	Comparisons between different countries are presented specially for commercial buildings	Commercial building	Energy consumption (primary energy consumption, CO_2 emissions and world population), global energy indexes (population, GDP, per capita income, primary energy, final energy, electrical energy, per capita primary energy, per capita energy emissions, primary energy intensity, final energy intensity), end use energy consumption, energy resources which were used for low temperature applications	Comfortable temperature, indoor temperature, reference temperature, air temperature, high temperature,
Chetan Agarwal et al. (2002)[10]	Compare the strengths and weaknesses, focus variables, independent and dependent variables, model type and their spatial and temporal characteristics of 19 land-use models	Land-use change models: 1. General Ecosystem Model[11]; 2. Patuxent Landscape Model[12]; 3. CLUE Model (Conversion of Land Use and Its Effects)[13]; 4. CLUE-CR (Conversion of Land Use and Its Effects – Costa Rica)[14]; 5. Area base model[15]; 6.	Flow of matter and energy in human ecosystems, physical laws of material and energy conservation	CLUE model has variables of temperature and precipitation

Citation	Research Method	L	E	T
		Univariate spatial models[16]; 7. Econometric (multinomial logit) model[17]; 8. Spatial dynamic model[18]; 9. Spatial Markov model[19]; 10. CUF (California Urban Futures)[20]; 11. LUCAS (Land Use Change Analysis System)[21]; 12. Simple log weights[22]; 13. Logit model[23]; 14. Dynamic model[24]; 15. NELUP (Natural Environment Research Council)[25]; 16. NELUP - Extension[26]; 17. FASOM (Forest and Agriculture Sector Optimization Model)[27]; 18. CURBA (California Urban and Biodiversity Analysis Model)[28]; 19. Cellular automata model[29]		

L. White and B. Noble[2] has investigated the land use and energy relation through strategic environmental assessment. Saleh Mohammandi et al.[3] researched using top-down and bottom-up supply model comparing their characteristics: feature models, year, spatial scale, temporal dimension, renewable energy source, analysis method. Demand model's top-down approach: macro level, variables used in the models (socioeconomic variables, climatic conditions, stock building construction rates etc.), econometric and technological models. Demand model's bottom-up approach: micro level and build up based on the data on an individual level to investigate the contribution of end user on energy usage in urban and regional level, evaluating the energy consumptions of groups of buildings (residential, commercial or industrial buildings) as distinct categories. As for spatial evaluation of energy demand it contains: GIS and remote sensing for data extraction and management. Integrated modeling approach: Energy and Environmental Prediction (EEP) model, Solar Energy Planning (SEP), LT-Urban model, SUNtool (decision support system for designers, CitySim (sophisticated simulation of source flow in neighborhood level), EnerGIS (GIS based urban energy model), MORPHOLOGIC model, SynCity. J. Gil and J. Duarte[4] used analytical framework to review the papers of sustainable urban development and building energy assessment. H. Zhao and F. Magoulès [5] predicted different types of building, its influence on energy demand and temperature. C.S.B. Grimmond et al.[6] identified modeling approaches that minimize the errors in the simulated fluxes of the urban energy balance. Diana E. Bowler et al.[7] has used the systematic review to evaluate the relationship of urban greening and temperature. L. Swan and V.[8] Ugursal tested the relationship of residential buildings and energy end use. L. Pe´rez-Lombard et al.[9] focused on comparisons between different countries of its comfortable temperature and energy demand specially for commercial buildings. Chetan Agarwal et al. [10] has executed SWOT analysis and their spatial and temporal characteristics of 19 land-use models.

3.2 Temporal simulations

KNMI is the abbreviation of Royal Netherlands Meteorological Institute, which collected the weather data throughout the whole Netherlands's and deduced the scenarios for the future weather in the Netherlands till 2085[30]. KMNI'14 climate scenario has listed the impact of climate change on the aspect of costal impacts, flooding, water resources, health, mobility, energy, agricultural, nature and recreation. The impact of climate to energy is the main focus part of this research. It is expected that in the winter time, the energy consumption for heating houses, factories and offices will increase, whereas in the summer time, more energy will be required for air conditioning; cooling water supply for electricity production will reduce. Other than the future scenarios from KNMI'14[31] and KNMI'06, a review of the EU's environmental agenda has been reviewed here. A comparison table (Table. 2) has clarify the different focus of different policies, which contains the aspects of land, energy, temperature and methods.

Table. 2 The L-E-T correlationship with focus on temporal simulations

Citation	Research Method	L	E	T
KNMI'14 Climate Scenarios for the Netherlands (2014)[30]	Scenarios to predict future weather 2010-2085: four scenarios of global temperature rise and air circulation pattern (G_L, G_H, W_L, W_H)	Land use changes, building density, vegetation prevalence	Energy consumption for heating and cooling	Global temperature rise, year mean temperature. Four seasons temperature: mean, year-to-year variation, daily maximum/minimum , coldest winter day per year, mildest winter day per year , number of frost days (min temp < 0°C), number of ice days (max temp < 0°C), number of summer days (max temp ≥ 25°C), number of tropical nights (min temp ≥ 20°C)
KMNI'14: climate change scenarios for the 21st century- A Netherlands perspective (2014)[31]	Scenarios prediction: Climate Explorer of KMNI (climexp.knmi.nl), 5th Coupled Model Intercomparison Project (CMIP5) data portal (cmip-pcmdi.llnl.gov/cmip5/data_portal.html)[32], EC-Earth model[33], regional climate model RACMO2[34]	Land use from 2000 up to the year 2100	Simple energy model, fossil energy use, energy storage in the ocean, turbulent kinetic energy, convective available potential energy (CAPE), energy supply, wind energy generation	Global mean temperature (1981-2010, 2016-2045, 2036-2065, 2081-2100), daily, monthly, seasonal, annual, 30 yr period temperature, air temperature, atmospheric temperature, surface temperature
Climate change in the Netherlands; Supplements to the KNMI'06 scenarios (2009)[35]	KMNI'06 scenarios. The rapid warming in the Netherlands and Western Europe is best accounted for in the W/W+ scenarios. The increase in the intensity of heavy showers is well described in the G/W scenarios. Provide	Greenhouse gasses and particulate matter about land use, land use and social economic factors.		Global mean temperature, temperature rise, annual mean temperature, sea surface temperature, land temperature, daily mean temperature, annual cycle of

Citation	Research Method	L	E	T
	guidance for the follow-up research that must lead to a next generation of KNMI climate scenarios for the Netherlands around 2013	Changes of evaporation are related to changes in soil, land use, water management		temperature for the current climate, temperature reconstruction for the 'Low Countries'[36]
Climate in the 21st century-four scenarios for the Netherlands (2006)[37]	The global temperature rise calculated by global climate models (gcms) has been used for constructing the new climate scenarios for the Netherlands. Additionally, it was analyzed how the air circulation patterns above Western Europe could change based on data from the same climate models. These global large-scale projections have extended changes in temperature, precipitation, evaporation, wind, and sea level in the Netherlands. Regional climate models (rcms) for Europe were used in addition to long-term observational series from Dutch stations.		Energy use for heating (house, factories, and office), wind energy production	Average annual temperature, minimum/ maximum temperature, global mean temperature, winter/ summer temperature, increase of temperature
A review of the EU's environmental agenda (2004)[38]	Scenario prediction. Review EU policies and their relationship with environment. Compare the observed data of GHG in the EU-25. Investigate the eco-efficiency of the material-waste chain in the EU. To achieve the policy of EU in the healthier environment regulation.	Land use: enlarged and intensified agriculture, forest exploitation, built-up area and infrastructure, remaining biodiversity. Increased and intensified land use through urbanizasion, agriculture, forestry and pollution. Regional land use policy. Land use change	Energy-efficient production, energy use from paper aluminium, steel and plastic production, bioenergy, energy crops, CO_2 emissions related to consumption and production	The EU has set a long-term target to restrict global temperature increases to a maximum of 2 °C compared to pre-industrial levels

Table. 3 The L-E-T correlationship research in specific research areas

Citation	L	E	T	Research Method
Bert G. Heusinkveld et al. (2014)[39]	v		v	In order to research the land use influence of the spatial variability of the Rotterdam urban heat island, mobile micrometeorological station mounted on a cargo bicycle has applied to record the real weather data. A bicycle measurement descending algorithm was assumed to be linear and similar at each location, thus this assumption limits the measured accuracy but is expected to be far better than the start-end difference
G.J. Steeneveld et al. (2014)[40]	v		v	Using the data from hobby meteorological observations, fixed station in Rotterdam to examine the relation between UHI and open water fraction (OWF), then developed an algorithm for water detection per pixel
W. Leduc and F. Kann (2013)[41]		v	v	The tested model of method is at neighborhood scale, Kerkrade-West, The Netherlands. Spatial planning based on urban energy harvesting toward productive urban regions. Method consists of six steps: land-use inventory; energy demand inventory; local renewable/ residual energy potential analysis; clusters of spatial functions exploration; energetic linkages analysis; network patterns exploration.
J. Kim, J. Guldmann (2013)[42]	v	v	v	Discuss the relationship of land-use planning and the urban heat island. The influence of the neighboring cells to central cell of its temperature is the main focus. The relationship of land uses has be discussed using normalized difference vegetation index (NDVI) and land surface temperature. A regression model has described these relationship.
B. Howard et al. (2012)[43]	v		v	This paper builds a model to estimate the building sector energy end-use intensity (kwh/m2 floor area) for space heating, domestic hot water, electricity for space cooling and electricity for non-space cooling applications in New York City. The model assumes that such end use is primarily dependent on building function, whether residential, educational or office for example, and not on construction type or the age of the building. The modeled intensities are calibrated using ZIP code level electricity and fuel use data reported by the New York City Mayor's Office of Long-Term Planning and Sustainability.
L.W.A. van Hove et al. (2011)[44]	v		v	19 cities in the Netherlands have been investigated: compare air temperature difference between cargo bike and reference station, compare number of habitants and UHImax values (K)
Janssen, Stijn J. (2011)[45]	v		v	Use quantitative approach (cell analysis) to investigate the influences of urban morphology on the average temperature of Rotterdam city
Bert van Hove te al. (2011)[46]	v	v	v	Use special design traverse measurement bicycle (Cargo bicycle). The inputs required to run the models consist of three general types: 1.Site-specific parameters to describe the surface morphology and materials; 2. Time series of atmospheric or forcing variables as boundary conditions; 3.Initial conditions required to initiate the model runs (spin-up)
Lily A. House-Peters and Heejun Chang (2011)[47]	v	v	v	Three downscaled climate warming scenarios and two land cover change scenarios (sprawl and dense) for the 2040s were used as inputs for an urban energy balance model, the Local-Scale Urban Meteorological Parameterization Scheme (LUMPS). Based on the surface energy fluxes simulated by the LUMPS model, it is calculated that the combination of the sprawl scenario with the 3◦C temperature rise increases external water consumption by 4061 L per household for August
Maarten Wolsink (2003)[48]	v	v		Discuss the Planning System and its impact on sustainable urban form and energy demand. Focus on the way knowledge of local conditions ('situated knowledge') is used in planning, which will be illustrated with examples of the significance of using such knowledge

3.3 Specific research areas

In this section analytical model for specific research areas are investigated. The investigation of the articles are targeted on the Netherlands since different climate will cause different city formation, energy demand and supply. The selected articles based on the following rules: the paper from the same author has been viewed only the most recent one. However, there are some articles which have representative roles so they have been examined as well. The correlationship of temperature and land use/ cover are more interested for researchers. Table. 3 presents the L-E-T co-relationship which has been studied in the analytical papers.

4. Results and discussion

This paper has explored the urban model focusing on the land use, energy, and temperature. There are three main types of paper, namely papers with a focus on: the spatial dimension, the temporal simulation, and specific research areas. For the reviewed papers, there are more than half papers that have researched the correlationships between land, energy and temperature. The methods has used to investigate the relationships, the spatial scales of research, the variables when doing simulation, and scenarios for land use can be concluded as following. Most of the methods used to derive relationships are:1) statistical analysis: linear regression, multiple regression, ordinary least squares regression; 2) engineering method, and a few 3) neural network and grey model. The spatial scales that investigated in these papers are: 1) neighborhood scale, 2) zip code, 3) census block, 4) cells author defined size. For the variables to simulate the relationships are dependent and independent variable, among these the dependent variables are: 1) temperature, 3) energy usages, 4) water usage 5) surface energy balance. Independent variables that represents spatial variation: 1) density of the habitants, 2) NDVI, or fraction of vegetation, building, water, 3) building density, 4) land use function, etc. For the simulation analysis, some scenarios for land use changes are: 1) sprawl, 2) dense. For the future study, researchers can combine these elements to propose a new urban modeling that focus on land use/cover, energy, and temperature.

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