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Adapting Epidemiological Methodologies to the Prediction of Health Effects of Built Environment Interventions

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Abstract: The influence of built environments on vitality and productivity of users is paramount. Since the introduction of Industrial, Flexible and Demountable Building, domotics, smart buildings, in general: mass-produced, intelligent and learning built environments, tailored built environments are within reach. This has resulted in the need for methodologies to predict short-term and long-term health effects of different built-environment constellations. Epidemiology has developed and validated methods to assess changes in prevalence of inflictions and other unhealthy conditions, as well as the number of healthy and vital years in a life span. After analysing the relationships among building (services) parts and its combinations, health determinants (exposures) and health outcomes, we could adapt the healthy years assessment (DALY) to changes in construction (insulation, air tightness) and building services engineering (ventilation, heating) for dwellings under Dutch conditions. The most important conclusion is that natural ventilation, mechanical ventilation and balanced ventilation not only differ in their average health effect, but even more so in the size of the ranges of these effects. Other systems, such as heat pumps or photo voltaic cells are expensive but will become economically applicable when healthcare costs are taken into account. These outcomes gave valuable clues for product innovation and opened the possibility to model health in relation to built environments. The method could also be applied to quality classification systems for dwellings.

1. INTRODUCTION

The influence of built environments on vitality and productivity of users is paramount. Since the introduction of Industrial, Flexible and Demountable building technologies (IFD, http://www.ifd.nl; Gassel, 2003), domotics, smart buildings, in general: mass-produced, intelligent and learning built environments, tailored built environments are within reach. Adaptive and adaptable systems became known as Ambient Intelligence (Marzano and Aarts, 2003). A need exists to predict both short-term and long-term health effects of different built-environment constellations.

Risk inventory evaluations and other tools are usually too vague to assess specific built environment characteristics. In the medical domain morbidity and mortality have been used to construct quantitative parameters for healthiness and disease of environmental conditions.

The Disability Adjusted Life Years (DALY) concept accounts for both acute and chronic effects and tends to include all known health changes (Stouthard, Essink-Bot, et al., 2000). Before building interventions are performed, the expected improvement should preferably be known.

This research aims at modeling health effects as a result of building characteristics by adapting the DALY concept to a risk evaluation tool.

2. METHODOLOGY

The Disability Adjusted Life Years (DALY) methodology has been developed by the World Health Organisation to evaluate the burden of disease to underpin policy-making (Murray and Lopez, 1994). The DALY-construct assembles three major aspects of public health: i) the loss of lifespan due to premature death, ii) the duration of living in reduced health by a specific disease, and iii) it standardises for the severity of diseases.

We adapted the DALY methodology to changes in building construction (insulation, air tightness) and building services engineering (ventilation, heating) for dwellings under Dutch conditions.

Health effects were selected that are known to be influenced by built environments (Bronswijk, Koren, et al., 1999; Koren, Pernot, et al., 2001; Kort, Koren, et al., 1997). The 5 most contributing diseases to the building-related disease load are (in order of importance) asthma, coronary hart disease, COPD (bronchitis and lung emphysema), lung cancer and pneumonia. Calculated dwelling-related disease loads in DALY are 26,134, 17,408, 14,792, 5,135 and 3,750, respectively, based on national disease figures (Hoeymans, Poos, 2002) and an estimation of the dwelling-related part. Total disease load attributable to dwellings was calculated to be 70,094 in the year 2000 (Pernot, Koren, et al., 2003).

We investigated 11 combinations of 21 building intervention measures intended to be energy reducing, together with 5 other building characteristics. Source character and type of exposure for each individual building measure was determined, and an estimate was made to what extent this would increase or reduce present mean exposure, assuming that this measure was implemented in all Dutch dwellings (Figure 1).

Changes in exposure may be due to technological or behavioural causes. For instance, an increase in a certain pollution source may be due to emitting building materials, polluted ventilation ducts or ill-treatment of ventilation facilities.

Exposure from an individual source is assumed to be the product of the source intensity, duration of exposure and sensitivity of the exposed person.

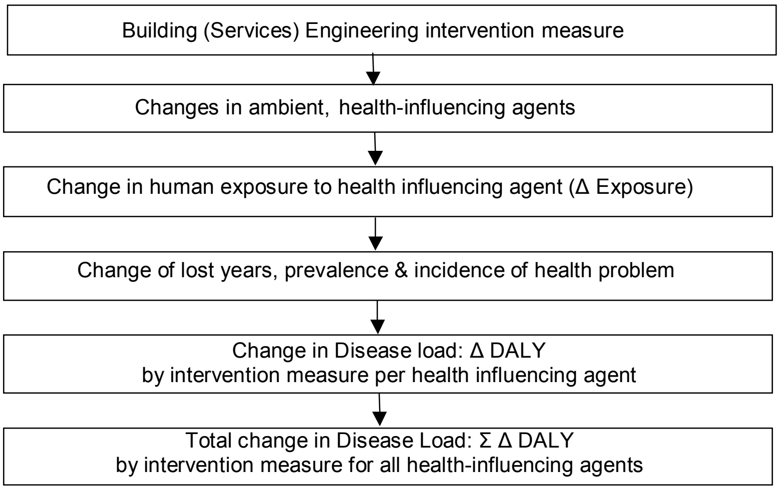

Figure 1. Flow diagram for the assessment of Disease-Load changes expressed in Disability Adjusted Life Years (DALY)

Considering the population of the Netherlands, the sensitivity is the mean of all individuals and has been kept constant. The duration of exposure will usually also be constant among the different interventions, as long as household behaviour is not influenced. Thus exposure depends on intensity of source.

Change in exposure leads to change in prevalence of disease and number of lost years, summed to ΔDALY. For all relevant sources together the sum of each ΔDALY is the total disease load of a single building intervention measure.

In the Dutch building regulations an energy performance coefficient (EPC) exists, which is the quotient of the calculated yearly energy use of fossil fuel (for heating, ventilation, hot water, lighting and cooling) and a normalized energy use. In the current Dutch Building Directive the actual EPC value for dwellings is 1. It is expected to be decreased to 0.8 as of 2006.

In table 1 an overview is given of the different combinations of constructional and building system elements that we used in this research.

Table 1. Overview of 11 interventions in dwellings in the Netherlands

#	**Description***	**Implementation**	**EPC value**
A	Naturally ventilated; heating by vented gas stoves	Traditional <1965	>1.0
B	Central heating; mechanical exhaust	1965-1995	>1.0
C	Central heating; mechanical exhaust; outer walls / floor / roof Rc = 3; $qv_{10} = 200.10^{-3}$ m^3/s	1995-2004	1.0
D	Balanced ventilation, 90-95% heat recovery; $qv_{10} = 100.10^{-3}$ m3/s	1995-2004	1.0
E	Mechanical exhaust; heat pump boiler; 2 m^2 photovoltaic elements	Jan Olierookstraat, Poeldijk	0.8
F	Balanced ventilation, 90-95% heat recovery, gas-heated boiler (96% energy efficiency); enlarged radiators	Tuindorp laag, Zoetermeer	0.75
G	Balanced ventilation, 90-95% heat recovery; total energy system; photovoltaic elements	Seniorenwoning, Harderwijk	0.65
H	Demand-controlled ventilation; gas-heated boiler (96% energy efficiency); floor/wall heating; heat pump boiler; solar collector; 2 m^2 photovoltaic elements	Buizengat, Vlaardingen	0.5
I	Demand-controlled ventilation; heat pump; floor/wall heating; solar collector	Spoorwijk, Den Haag	0.5
J	Balanced ventilation, 90-95% heat recovery; high performance boiler; floor/wall heating; solar collector	Nieuw Terbregge, Rotterdam	0.5
K	Balanced ventilation, 90-95% heat recovery; heat pump; enlarged radiators; solar collector	VOS Project-ontwikkeling	0.5

* Rc = Heat resistance coefficient of the construction, expressed in $m^2.K/W$; qv_{10} = airtightness, expressed as airflow through building envelope at a pressure difference of 10 N/m^2.

3. RESULTS

A 100% implementation of common building practices can only have a small effect on present-day disease load. They are already used to almost their complete capacity (Interventions A and B). In these cases the range is also small because all are well known (Table 2). For newer interventions like balanced ventilation, actual exposure has not yet been studied thoroughly, and exposure changes are based on more rough estimates.

Table 2. Single intervention measures and their current prevalence in the Dutch dwellings (Veld and Gids, 1999)

Building part	**Measure***			**Prevalence in %**
Air tightness	Ground floor < 10 cm^2 leakage surface			<1
	Window or door < 15 cm^2 leakage surface			<1
Heating system	Water-filled radiators,	small, 70/90ºC		75
		large, 40/55ºC		<1
	Vented gas stoves			10
	Floor or wall with warm-water ducts, ≤ 28ºC			10
	Air heating			5
	Central heating boiler	96% energy efficient (type HR107)		5
		96% energy efficient + 2 m^2 solar collector		<1
		With heat pump		<1
		With heat pump and 2 m^2 solar collector		<1
		Solar collector	warm tap water <2 min heating ≥60ºC	<1
			warm tap water >10 min heating ≥60ºC	<1
		Total energy system		<1
		With 2 m^2 photovoltaic cells		<1
Thermal insulation	Façade + roof + floor	Rc = 3 ; U = 0.31		<1
		Rc = 4; U = 0.24		<1
		Rc = 5; U = 0.19		<1
	Window panes U = 1.2			2
	Front and back door U-value max. 1.2			1
Ventilation system	Mechanical exhaust of bathroom, kitchen, toilet			53
	Natural			46
	Balanced ventilation with 60 to 95% heat recovery			1
	Demand-controlled ventilation			<1
Other	North-south oriented façade			60
	Closed sun-lounge			<1

Rc = Heat resistance coefficient of the construction, expressed in m^2.K/W;
U = Heat transfer coefficient, expressed in W/m^2.K

To strengthen the estimates for the newer interventions, 3 situations were viewed (Figure 2). First an optimal situation, in which no installation flaws are made, maintenance is regular and adequate, and user behaviour is positive. The second situation is the most likely situation: flaws in installation are present here and there, maintenance fails now an then depending on costs and time expenditure, and the systems are occasionally misused. The third situation is the worst-case scenario: installations are regularly inadequately installed (because of bad or complex design), maintenance is neglected more often than in current systems, and users often put off systems or use them not according to the demands of the design.

Using these points of departure, for each building measure and each relevant disease the change in disease load compared to the current situation could be estimated (Figure 2).

Some of the solar collector systems for tap water (as incorporated in interventions I to K) may induce an extra disease load. These systems are difficult to keep *Legionella*-free, and induce in that way an extra health risk compared to more traditional tap-water heating systems.

Natural ventilation (A), mechanical ventilation (B, C, and E) and balanced ventilation (D, G, J, and K) not only differed in their average health effect, but even more so in the size of the ranges of their effects. The range in the disease load of balanced ventilation systems is derived from various aspects in the actual design, variation in installation and maintenance, maintenance contracts and performance, and the yet not well-known user behaviour.

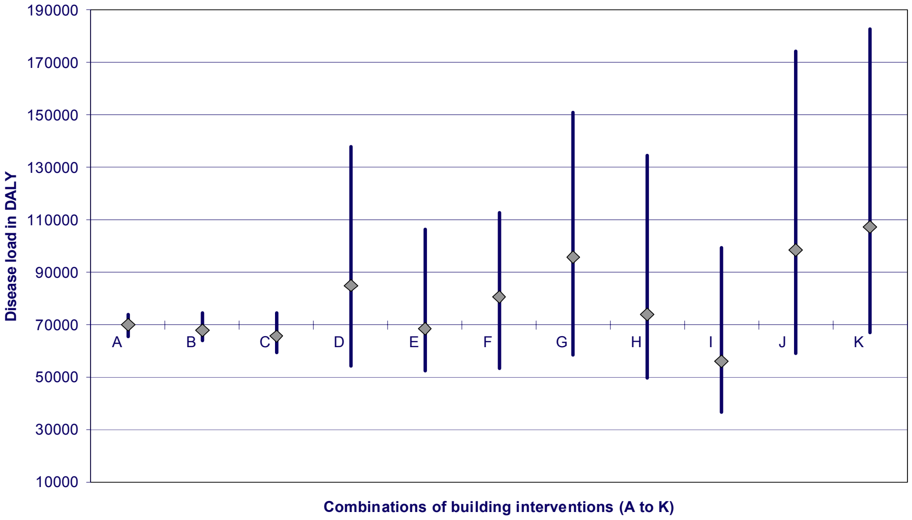

Figure 2. Disease load for 11 interventions (A to K), assuming a 100% implementation in the Dutch dwelling stock. The modus is shown as a ◆.

For each of the combinations of the building (services) measures, as described in table 1, estimations of maximal, minimal and modal disease load were made (Figure 2).

4. DISCUSSION

The lower edge of the columns in figure 2 indicates perfect installation, maintenance and user behaviour, which are utopias. The actual level to be expected, the modal variant, has been estimated from current knowledge of user behaviour, flaws in installation and maintenance performance. The top end of the columns in figure 2 indicates a situation that could result when systems are rapidly introduced, without much attention for the prevention of building-attributable health effects, as is common nowadays.

The bandwidth in health effects of individual measures and of complete interventions is a result of the three-situations methodology. The measures that are most frequently applied at present are time tested. Installation performance, maintenance and user behaviour are known to a great extent, the whole has been adapted to needs and capabilities of both users and engineers. This results in a comparatively small range (Interventions A to C).

The more recently introduced systems are less studied. To both the user and the installation and maintenance engineer they are new resulting in more extensive errors and even misuse (Interventions D to K).

Nevertheless, a system design that reduces installation flaws and facilitates maintenance and positive user behaviour could increase the health potency of a building in case of intervention I (including demand-controlled ventilation).

Some individual measures like heat pumps and photovoltaic cells are yet too expensive to be applied nationwide although they are desirable from a health point of view since no health decreasing effect is expected. If healthcare costs were taken into account, these systems would be competitive to other measures.

In systems that support decisions in the design stage, it would be useful to include health implications. A health-effect module could also give valuable clues as to product innovation. In the future, more epidemiological methodologies should be adapted and fine-tuned to the evaluation of built environment design and interventions.

The method developed in this research could also contribute to a classification system for dwellings, giving the user (client) the possibility to choose for a dwelling of known health implications.

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REFERENCES

Bronswijk, J.E.M.H. van, L.G.H. Koren, F.A.M. Horst, M.M.L.F. van Laere, I.P.M. Nillesen, C.E.E. Pernot, and G. Schober, 1999, *Gezond en Duurzaam Bouwen: GeDuBo,* Report Eindhoven University of Technology, nr. BMGT99.083, Eindhoven. http://www.phe.bwk.tue.nl/

Dongen JEF van, H Vos, 2003, *Relatie EPC-niveau en zelf-gerapporteerde gezondheidseffecten. Analyse op basis van geïntegreerde data uit twee onderzoeken*' rapport 2003-46. TNO INRO, Delft. ISBN 90-5986-041-1

Gassel, F. van, 2003, Experiences with the Design and Production of an Industrial, Flexible and Demountable (IFD) Building System. Results of the study. BFRL Publications Online, Building and Fire Research Laboratory, National Institute of Standards and Technology, Gaithersburg, MD 20899. http://fire.nist.gov/bfrlpubs/build02/PDF/b02153.pdf

Hoeymans, N., M.J.C. Poos, 2002, 'Sterfte, ziekte en ziektelast voor 49 geselecteerde aandoeningen'. In: Volksgezondheid Toekomst Verkenning, Nationaal Kompas Volksgezondheid. Bilthoven: RIVM, http://www.nationaalkompas.nl

Koren, L.G.H., C.E.E. Pernot and J.E.M.H. van Bronswijk, 2001, *Gezondheidsrisico's van ventilatiesystemen in woningen,* Report Allergo Consult AC-2000/2/WK, 30 juli 2001, Beusichem NL.

Kort, H.S.M., L.G.H. Koren, C.A.F.M. Bruijnzeel-Koomen, I.P.M. Nillesen, and J.E.M.H. van Bronswijk, 1997, *Van binnenmilieu-klachten tot gezondheids-classificatie van nieuwe en te renoveren woningen (GCW) 1: Van ziekten en klachten, naar bouwkundige kenmerken*, Report Eindhoven University of Technology, nr. BMGT96.508, Eindhoven. http://www.phe.bwk.tue.nl/

Murray, C.J. and A.D. Lopez, 1994, 'Quantifying disability: data, methods and results', *Bull World Health Organ* 72(3):481-94

Pernot, C.E.E., L.G.H. Koren, J.E.F. van Dongen, J.E.M.H. van Bronswijk, 2003, '*Relatie EPC-niveau en gezondheidsrisico's als onderdeel van het kwaliteitsniveau van gebouwen'* Report 2003-GGI-R057. TNO Bouw, Delft. ISBN 90-5986-047-0

Stouthard, M.E.A., M.L. Essink-Bot, G.J. Bonsel on behalf of the Dutch Disability Weights Group, 2000, 'Disability weights for diseases. A modified protocol and results for a Western European Region', *Eur.J.Public Health* 10:24-30.

Veld, P. Op 't, en W.F. de Gids, 1999, *Techniekinventarisatie Ventilatie*. Report. Novem, Sittard