Trias Exergetica
a new strategy towards a zero-energy built environment

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Summary

The well known *Trias Energetica* (reduce demand, use renewables, use conventional fuels as efficient as possible) has been a useful approach towards more sustainable buildings during the last decade and half. However a drawback of the method is that several important aspects are not addressed. Amongst others It does not address the quality of the energy needed and provided and it does not address the different scales within the built environment (building, neighbourhood, city, region, etc.). These aspects are relevant if we want to find optimal solutions for the built environment as a whole.
Introducing the concept of exergy (quality of energy) seems to be a promising additional concept to tackle these aspects, give more insight and provide optimization strategies on different scales of the built environment. Related ongoing Dutch research projects are discussed as well as first attempts to introduce the LowEx approach in practical instruments in the Netherlands. The *Trias Exergetica* is proposed as a sustainable strategy towards a zero energy built environment.

Keywords: Exergy, Strategy, Zero-Energy, Built Environment, Policy

1. Introduction: Trias Energetica

During the last one and a half decade the *Trias Energetica* has become one of the key strategies towards a more sustainable built environment in the Netherlands. This strategy has been introduced by Novem (the Dutch Agency for Energy and the Environment; one of the predecessors of NL Agency) back in 1996 [1].

The three elements of the *Trias Energetica* are:
1) Reduce the demand for energy;
2) Use renewable sources of energy;
3) If fossil fuels are still needed use them as efficient and clean as possible.

Although this approach has been, and still is, very useful, a drawback of the method is that several important aspects are not addressed. Among others it does not address the quality of the energy needed and provided and it does not address the different scales within the built environment (building, neighbourhood, city, region, etc.). These aspects are relevant if we want to find optimal solutions for the built environment as a whole.

2. Exergetic thinking / the Low Exergy approach

Introducing the concept of exergy (quality of energy) seems to be a promising additional concept to tackle these aspects, give more insight and provide optimization strategies on different scales of the built environment.

Around the turn of the millennium Novem was running a *national market introduction programme for low temperature heating systems* [2][3]. The main rationale behind this programme was that low temperature systems (LTS) would form an essential stepping stone towards a more sustainable energy supply in the built environment in the future. Whatever the energy source, a low temperature heating system will perform better than the traditional high temperature system (HTS). For most renewable sources the efficiency will even be much better (e.g. heat pumps), or a LTS is a prerequisite because the required temperature level for a conventional HTS (90°C) is simply not available (e.g. low-temperature geothermal energy). It was perceived that the relatively moderate investment into low temperature emission systems was feasible in almost all cases, whereas the investment needed for a renewable heat source would be too high in many cases. By introducing LTS on a large scale, all these buildings would be ready for the future. Even if the choice was made for a conventional heat source like a condensing boiler, the system would be ready for a more sustainable or renewable heat source at the end of the boilers technical lifetime (in 15 years); no inherent blockades would be introduced. Low temperature systems make houses flexible and ready to use low valued (low temperature) heat sources in future.

At the same time one started to realize that the conventional way of heating houses in the Netherlands, i.e. burning natural gas in condensing boilers, was probably not as efficient as the labels promised (one could buy a HR107 condensing boiler with an energy efficiency of 107%; related to net caloric value of course). Burning natural gas at several hundred degrees to make hot water of 90°C to heat your house to a temperature of 20°C; somehow every layman could feel that something is not right here, and that a label stating 107% energy efficiency cannot be the whole story.

And in fact it isn't ! In 1956 the Slovenian mechanical engineer Zoran Rant introduced the concept of exergy [4]. The term exergy originates from the Greek words *ex* and *ergon*, meaning *from* and *work*. Exergy is defined as the maximum amount of work that can be produced from a stream of energy or matter, as the medium comes into equilibrium with its surrounding environment.

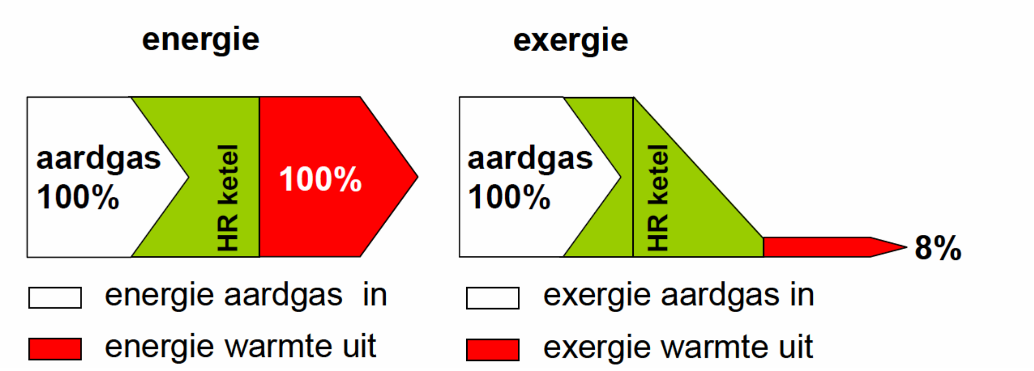

Figure 1 *Energy and exergy flow diagrams for a natural gas fired condensing boiler. (Translation of the Dutch words: energie=energy, exergie=exergy, aardgas=natural gas, HR-ketel=condensing boiler, warmte=heat, in=in, uit=out). Source: Cornelissen and van Rens (2010) [5]*

If we analyse what happens in a condensing boiler from an exergy point of view [5] we find out that the fantastic energy efficiency of almost 100% (related to gross caloric value), has reduced to a mere 8% exergy efficiency !
We could have used a high quality fossil source like natural gas for a much higher quality purpose, and still have used the remaining waste heat to fulfil our low quality demand of heating our houses. Keeping in mind that heating in the Netherlands is provided for over 90% by gas fired boilers, the

exergy approach learns us in what an incredible (in)/efficient way we are using/destroying our high quality natural gas resources, day by day. Or to take the optimists approach: what an enormous potential there still is to improve our energy systems.

Although already well established in power plant engineering and within some larger chemical and oil companies, the exergy approach has only recently attracted interest in built environment related disciplines like architecture, building science and town planning. The IEA ECBCS Annex 37 *Low Exergy Systems for Heating and Cooling of Buildings* extensively describes the exergy approach or LowEx approach within the built environment in its final report in 2004 [6].
Shukuya [7] powerfully illustrates the nested structure of environmental space (shown in figure 2). Solar exergy enters the earth through the atmosphere and is gradually turned into entropy, as it passes through all different scale levels. At the same time the drawing illustrates the interconnectedness of all different scales, and as such the interconnectedness of global energy flows.

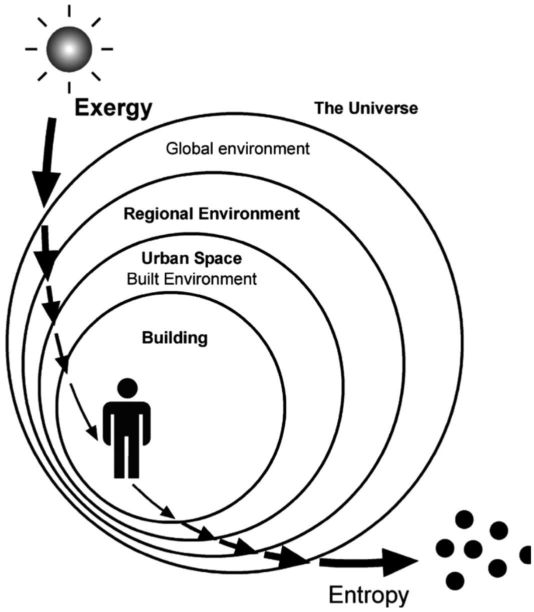

Figure 2 *Conceptual illustration of global energy flows. Solar exergy enters the atmosphere and is gradually turned into entropy. Source: Based on Shukuya (2009) [7]*

With this drawing and the concept of exergy in mind we can make the following observations:
(1) Human needs (demand) in the centre greatly influence the exergy destruction on all higher scales. A small reduction of the exergy need of the human already has a great impact on the total chain. Therefore reduction of exergy demand is an important factor.
(2) All scales are interconnected. Optimization needs an integral system approach. This means that reduction of exergy destruction should be considered at all different scale levels. It is not said that optimisation at the building level is always the best. Depending on the case a higher (or lower) level intervention could be a better one.
(3) Matching the quality of energy supply with the quality of energy demand (don't use high quality sources for low quality needs) is a key strategy in optimally connecting the scales.
(4) Reduction of exergy destruction is not only relevant for fossil fuelled systems, also in systems using renewable sources this is important, as also renewables have impact on land and material use, not to mention economic aspects.

While the first point is in line with (the first step of) the *Trias Energetica*, the latter three are not really addressed in the *Trias Energetica*. Exergetic thinking however can tackle these important aspects.

3. Ongoing exergy related research

Within the *Dutch national Energy Research Programme* (EOS), Built Environment is an important focus area [8]. This programme has been operational since 2005 and is carried out by NL Agency on behalf of the Ministry of Economic Affairs, Agriculture and Innovation. It is the central national programme for energy related R&D in the Netherlands. Apart from R&D into innovative components, integral system approach related research has been the main focus of the Built Environment focus area.
Within this part of the EOS-programme several extensive research projects have taken on research related to exergy. Two of these will be discussed shortly. Both of these projects have in common that they are carried out by a broad and multidisciplinary research consortium, which is probably a sine qua non if we want to investigate an integral system approach.

The *LowExNL* project (Exergetic system approach for an efficient, people-friendly and affordable use of energy in the built environment) is a joint project between the three Dutch technical universities of Eindhoven (TU/e), Delft (TUD) and Twente (UT) [9]. This project takes the human being as a starting point for its research, and investigates how a substantial reduction of the use of high quality energy resources in the built environment can be achieved, while still fulfilling the comfort needs of humans. The focus scales of this project range from the human being (thermal comfort issues) up to the building and neighborhood scale. TU/e takes on the thermal comfort of LowEx systems, TUD the integral approach of the exergy chain and UT focuses on cost aspects of LowEx systems. The project is also part of the Dutch contribution to the IEA ECBCS Annex 49 “Low Energy Systems for High Performance Buildings and Communities” [10] and it also participates in the European COSTeXergy project [11]. Intermediate results have been presented at different conferences and workshops, and final results are expected within a year’s time. More information is available at the project website [9].

The *SREX* project (Synergy between regional planning and exergy) takes the exergy approach to a higher system level, i.e. the city and even regional level [12]. The project studies in detail the possibilities to use exergy as a steering element in spatial planning. And as *spatial* planning should imply a 3-dimensional approach, it also studies the possibilities of using the underground (heat and cold storage, use of geothermal heat, etc.) for exergetic optimization.
The team consists of researchers from the universities of Groningen, Wageningen, Delft, and the university of applied science in Heerlen, in an exciting mix of disciplines ranging from landscape architecture, via spatial planning, to building science, complemented with geological experts. Interesting is also that the research is accompanied by two case studies on the regional level: one focussing on the northernmost provinces of the Netherlands (Friesland, Drenthe, Groningen) and one on the southernmost part (South-Limburg).
Intermediate results have been presented at different conferences and workshops and in a recent paper [13] from this project in the International Journal of Exergy five exergy-conscious design principles are proposed, which are summarized in Table 1. Research from this project also points out the impact of energy and material use on land use and proposes *embodied land* as an indicator [14]. It becomes clear that even in a future society fully powered by renewable energy sources, exergetic optimization remains crucial, to limit the impact of renewables on land use, and avoid unwanted competition with food supply.
In this project for the first time, at least in the Netherlands, exergy is discussed on this (regional) system level, and in relationship with spatial planning. Final results are expected within half a year. More information is available at the project website [12].

Table 1 *Exergy-concious strategies for planning and design of the physical environment. Source: Stremke, van den Dobbelsteen, and Koh (2011) [13]*

	Exergy-conscious strategy	*Building component*	*Building*	*Neighbour-hood*	*City*	*Region*
1	Increase exergy efficiency (e.g., heat recovery systems)	***	**	*	*	*
2	Decrease exergy demand (e.g., building orientation and passive house)	*	***	***	*	*
3	Increase use of residual exergy (e.g., residual heat for room heating)	*	**	***	***	**
4	Match quality levels of exergy supply and demand (e.g., cascade)	*	**	***	***	**
5	Increase assimilation of renewable exergy (e.g., geothermal)	**	**	***	***	***

*Less relevant

**Relevant

***Focal scale.

4. Practical application of the exergy concept; first attempts

The challenge will be to translate the knowledge generated in these research projects into practically applicable tools or instruments. Research is nice, but if the results cannot be used in real life, it doesn't help much our efforts to change the energy system into a (more) sustainable one. For the abovementioned research projects it is probably still too early to ask for concrete and directly usable spin-off. However, in parallel NL Agency has recently started to use the concept of exergy in two different initiatives.

In last year's (2010) national programme on industrial heat use (IWB), focussed on stimulating the use of renewable heat in and waste heat in or from industry, exergy has been used as one of the evaluation criteria for ranking projects and deciding about granting subsidy [15]. Details on the way this was done are given in [16].
In general one can say about the evaluation that:
(1) the less exergy losses and the better the temperatures of heat supplier (supply) and heat user (demand) would match the higher the score, and
(2) the higher the temperature of the waste heat, the heat recipient uses in its process the higher the score.
Next to other more conventional criteria like feasibility, cost effectiveness, CO_2-reduction, and reproduction potential, the exergy criterion was a crucial one as its score would be weighted double. This was the very first time ever that exergy was used as an evaluation criterion in any subsidy scheme in the Netherlands.

Recently another instrument has been developed by NL Agency in which the concept of exergy has been introduced. The *Dutch HeatAtlas* (WarmteAtlas) is a GIS-based tool; a comprehensive digital, geographical map of heat sources and heat demand in the Netherlands. On the supply side the user can find (potentially) suitable locations for deep geothermal energy, heat/cold storage, biomass and waste heat. On the demand side the atlas gives an overview of the heat demand of households, industry, green houses and commercial buildings.
The *Dutch HeatAtlas* is meant as an inspiration for new renewable or waste heat projects, can be used in all sectors, and stimulates synergy between special planning and energy on provincial and municipal level.
From an exergy point of view it is interesting that the atlas provides a quick insight in local heat demand, and the presence and quality of sustainable heat sources. The temperatures of the heat locally available are mapped (3 categories: high > 200°C, medium 120°C - 200°C, low < 120°C) as

well as the quality (temperature level) of the local heat demand. This is a good basis for an optimal exergetic matching of supply and demand.
With this instrument NL Agency wants to contribute to a transition towards a more sustainable heat supply in the Netherlands, and hopes to trigger concrete initiatives. The *Dutch HeatAtlas* is accessible freely on the internet since 23 march 2011 [17].

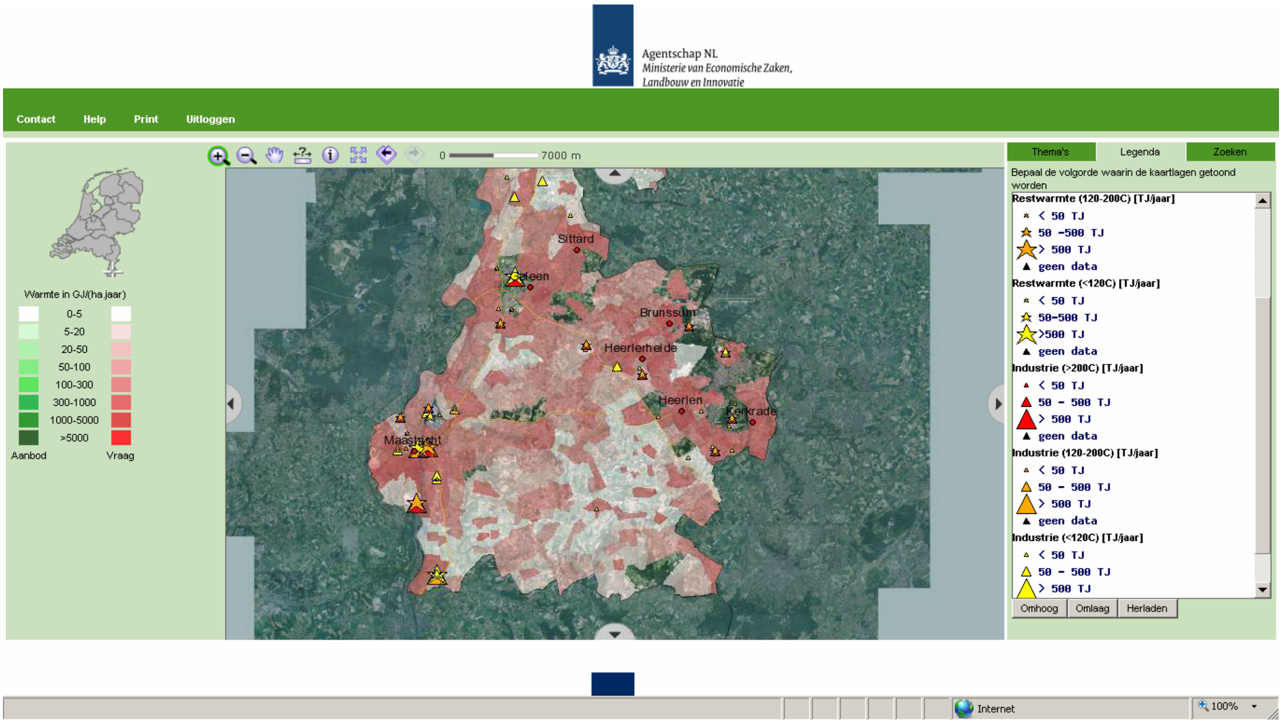

Figure 3 *Screenshot from the Dutch HeatAtlas showing waste heat sources and intensity of heat demand in the built environment, as well as heat demand in industry at different temperature levels, in the southernmost part of the Netherlands/Limburg ("Dutch Mountains").*
Source: www.warmteatlas.nl

5. Conclusion: Trias Exergetica

The well known *Trias Energetica* has been a useful approach towards more sustainable buildings during the last decade and half. However, a drawback of the method is that it does not address several important aspects that are important if we want to find optimal solutions for the built environment as a whole.

Introducing the concept of exergy (quality of energy) seems to be a promising additional concept to tackle these aspects, give more insight and provide optimization strategies over different scales of the built environment, matching supply and demand and minimizing losses in the system. Moreover, exergy can provide an unbiased evaluation of the energy systems in the built environment, based on laws of physics. Extensive research projects are currently focussing on this topic, and first practical instruments incorporating the concept of exergy have been presented.

Therefore the time seems ripe to bring the good-old *Trias Energetica* to a higher level by incorporating the Low Exergy approach. By definition (eq.1 and figure 4):

Trias Exergetica = (Trias Energetica + LowEx approach) (1)

The *Trias Exergetica* is proposed as an integral and objective strategy towards a zero energy built environment.

The challenge will be, to develop simple but adequate design and planning tools that will enable professionals to use this strategy in daily practise, and even more important, to apply these principles in real life to gradually convert our present built environment into a sustainable zero-energy one.

Time only will learn if the *Trias Exergetica* is to become an as well established and successful strategy as its energetic predecessor.

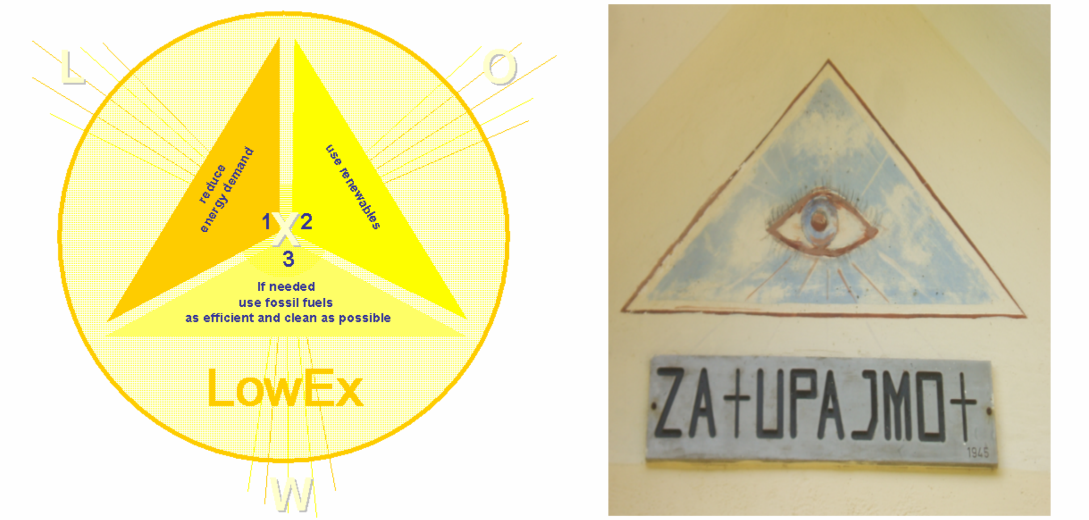

Figure 4 *Trias Exergetica (Trias Energetica + LowEx): a clear and integral view on zero-energy built environment.*

6. Acknowledgements

The Dutch research projects presented are funded through the National Energy Research programme (EOS) that NL Agency is carrying out on behalf of Dutch Ministry of Economic Affairs, Agriculture and Innovation. Also the Industrial Heat Use programme (IWB) and the *Dutch Heat Atlas* have been developed by NL Agency on behalf of the same Ministry.
The views and opinions of the author do not necessarily state or reflect those of the Dutch government or NL Agency.

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