LowEx

AN ATTEMPT TO MAKE IT EASIER-TO-UNDERSTAND

WHAT IS THIS THING CALLED "EXERGY"

Energy saving is - from a scientific point of view - nonsense. Energy is transformed from one form into another, but could never be consumed. But every energy-form consists of a valuable part, called exergy, and a worthless part, the anergy. The thermodynamic theory in form of the second law of thermodynamics states that it is impossible to convert anergy in exergy. But in every energy transform process a part of the exergy is converted in anergy and is in this way consumed, gone. So the problem of energy savings is really the question of the best way to save the biggest amount of exergy. Realising the following concepts, it is shown that we are not consuming energy, nor are we able to do "energy savings", it is exergy that we are consuming.

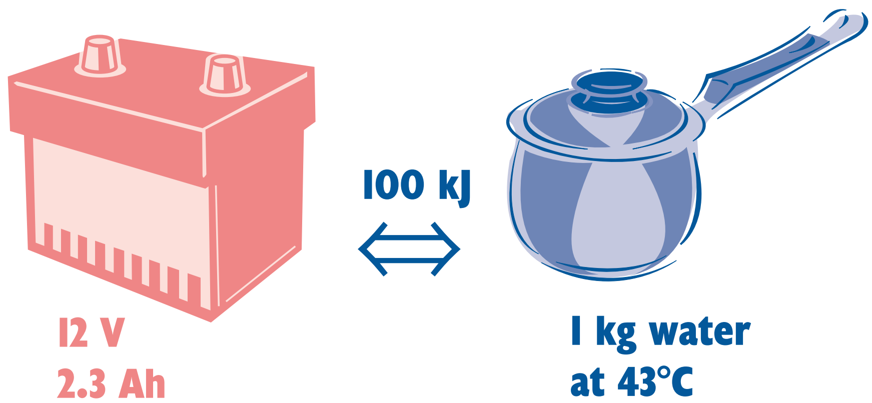

Figure 1. Both systems contain the same amount of energy but not the same amount of exergy.

EXAMPLE OF ENERGY QUALITY

The fact, that there is an energy quality is evident for us from our experience in daily live. It is obvious that 100 kJ electricity stored in a 12 V and 2.3 Ah car-battery is more useful, easier to transform in something useful for us than the same amount of 100 kJ energy stored in 1 kg water at a temperature of 43 °C, if the ambient temperature is 20 °C.

The first energy form is good for driving a machine, like a computer, drive a light bulb of 40 W in 42 min or at least to warm 1 kg of water with 23 °C. The energy in the second example is just good to wash our hands or do the dishes. We imagine that there is a difference in the energy, but it is not the amount, it is the quality!

IEA ECBCS ANNEX 37 LOWEX NEWS NO 2

This is the second issue of LowEx News - a newsletter that will be published twice yearly during the working phase of Annex 37 'Low Exergy Systems for Heating and Cooling of Buildings'. The first issue was published in September 2000.

During Annex 37 the participants are trying to promote rational use of energy by means of facilitating and accelerating the use of low valued and environmentally sustainable energy sources for heating and cooling of buildings. There are participants from ten countries (see last page).

Final product of the Annex will be a Design Guidebook for designers and architects. Other products will include technical reports and conference papers, national and international industrial seminars and a web-site with all the information about the Annex (see page 7).

AN ATTEMPT TO MAKE IT EASIER-TO-UNDERSTAND
WHAT IS THIS THING CALLED "EXERGY"...

THE EXERGY CONCEPT

The basic theories in thermodynamics tell us, in the first law of thermodynamics, that energy could never be destroyed and will be just transformed into other forms. But already at this point we realise that there are different forms of energy, like electricity, heat, mechanical power, light and that it is theoretically possible to transform these different types of energy into each other.

Carnot stated in the second half of the 19th century that there is a maximum efficiency for that transformation. Taking his founding as a basis we could state that some energy forms, like electricity or mechanical power, can be transformed with theoretically no losses (ordered energy) and others, like heat, only with a certain amount of loss in the transformation (disordered energy). We could say there is an energy quality, or a quality factor for energy. The most convenient standard of this energy quality is the maximum work, which can be produced from a given amount of energy in a certain form by use of the ambient parameters (temperature, pressure, etc.) as a reference state.

Introducing the term exergy we are paying respect to the fact that energy manifests itself by its quantity and its quality. Thus exergy is defined, as stated above, in relation to the environment. The environment has to be defined and it is considered to be large and its parameters and states are not affected by the system under consideration.

EXERGY ANALYSIS OF BUILDINGS

The "consumption" of primary energy in residential and commercial buildings counts for about one third of the total world energy demand and thus buildings represent consequently a major primary contributor to global pollution in the energy related fields. Even if big efforts have been made to reduce the energy consumption in buildings for example by constructing thermally nearly perfect envelopes, by improving the quality of window glazing and by using the thermal storage of the construction itself there is still a broad "saving" potential left. One way to utilise that could be the use of exergy analysis on buildings.

There are just a few examples for exergy analysis in the building sector. The result from one investigation is the fact that the major exergy loss for space heating is caused by the boiler. But this happens on the basis of the heat loss of the building, the quality of the building envelope. A good thermal insulation and a reduction of internal loads for the case of cooling are mandatory for a good low exergy design of buildings.

EASY TO UNDERSTAND: THE ENERGY QUALITY FACTOR

To make the term exergy easier to understand, every energy form can be qualified. The energy quality factor, or in other words the exergy content, of heat in relation to the temperature is presented in Figure 2.

The quality factor and also the exergy is zero at the reference temperature and increases with a bigger temperature difference between the source and the reference temperature. Since only the potential is important, there is cold and heat exergy. If the temperature of the source is higher than the reference temperature, heat exergy with certain quality factor is available.

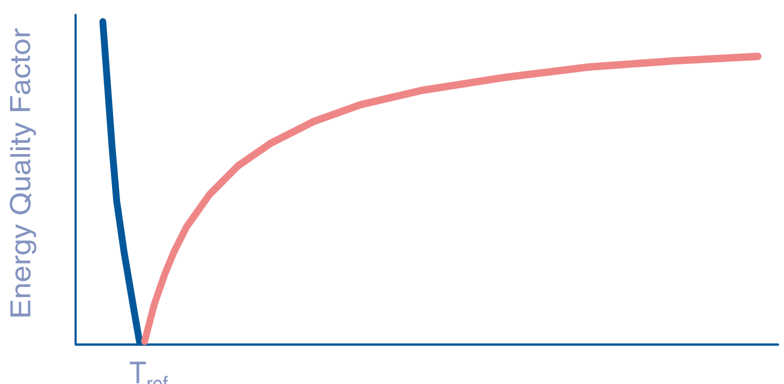

Figure 2. The energy quality factor of heat in relation to the temperature.

CONCLUSIONS

At least it can be stated as a conclusion that to open the way for more sustainable buildings it is mandatory to take all environmental impacts, also the ones from the utilised energy sources into account. Since exergy is a (re-)source itself, it should be taken into consideration!

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OCCUPANTS EXPERIENCES
IN DWELLINGS WITH LT HEATING SYSTEMS

One of the critical success factors for the implementation of Low Temperature Heating systems in residential buildings is the acceptation of the systems by the occupants. At this moment costs for LT heating systems for dwellings are higher than traditional HT systems while energy savings are in some cases marginal. This means that LT systems must have some additional qualitative benefits for occupants (thermal comfort, indoor air quality, safety, etc.). The overall performance of LT heating systems must be at least equal or preferably better than that of traditional HT systems. An occupants survey has been conducted in the Netherlands among 409 households with LT heating systems. The first objective was to make an inventory of the experiences of occupants with LT systems and to look if these systems fulfil their expectations. The results can also give insight in possible barriers for a further market introduction.

USE OF DWELLING AND PROVISIONS

Occupants were asked about the set points of the thermostats for a winter evening and a winter night. Objective of this question was to get an impression of the use of the different LT systems.

	T-average (°C) winter evening	T-average (°C) winter night
Floor heating	19.9	17.8
Wall heating	20.3	17.6
LT-radiators	20.6	15.1

For a winter night the difference in set points for radiators on one hand and wall and floor heating on the other hand is significant.

EVALUATION OF LT-SYSTEMS

Occupants were asked to mention the advantages and disadvantages of their heating systems.

Floor heating

Two projects had floor heating. In total, data of 52 dwellings was available. Floor heating was a major decision criterion for the selection of the dwelling as indicated by 71% of the households.

As advantages of floor heating were mentioned:

- constant, equal, pleasant heat, temperature, and comfort 50%
- no cold feet 31%
- no radiators 23%
- healthier, less dust and particles 6%

As disadvantages of floor heating were mentioned:

- slow heating up of the dwelling, sometimes too cold, sometimes too hot 35%
- limitation of selection of floor covering (no wood, laminate) 15%
- many failures during first year 8%

Wall heating

Wall heating systems were applied as main heating system in two projects. In total, data of 17 dwellings was available. 35 % of the households indicated that wall heating was a major decision criterion for the selection of the houses.

As advantages of wall heating were mentioned:

- no space needed for radiators 47%
- cleaner air 35%
- equal heat 35%
- no cold draft 12%
- low energy use 6%
- no dry air 6%
- no noise 6%
- better indoor climate 6%

As disadvantages of wall heating are mentioned:

- slow heating up of the dwelling 41%
- cold draft near windows with on places without tubes in wall 12%
- limitations of drilling in walls 6%
- no temperature control possibilities per room 6%
- no central point to warm up 6%

LT-radiators

Most of the selected projects have LT radiators. This group with 113 households is overrepresented in this survey.

As advantages of LT-radiators are mentioned:

- no idea that LT radiators are different from HT radiators 31%
- lower energy use 19%
- less burning of dust, less smell 7%

As disadvantages of LT-radiators are mentioned:

- no disadvantages 35%
- more space needed 27%
- radiators don't get really warm 7%
- ugly design 5%
- difficult to control (per room) 5%

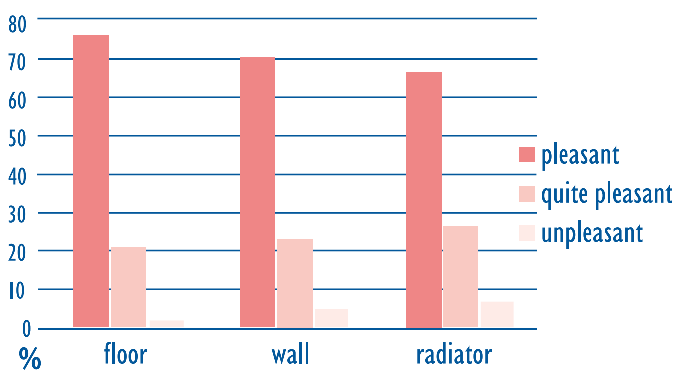
Failures of heating systems

The occupants were asked about the overall functioning of their heating system. Many households (44%) had failures with their heating systems during the first months of living in their new home. The occupants themselves could not repair these failures. Notable is that the most common system, LT radiators, had the highest percentage of failures (48%). Wall heating had the lowest score with 23%.

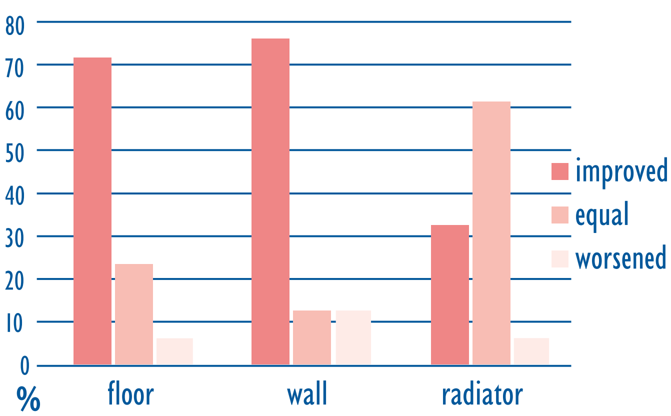
Appreciation of heat

The radiant temperature as well as the air temperature influence thermal comfort. However, it is difficult to translate the difference between air and radiant temperature to a level of appreciation. Occupants were asked to give their appreciation of the heat in a scale from very pleasant to very unpleasant. Floor heating scored a little better than wall heating. Relatively more occupants judged LT radiators as "quite pleasant" or "unpleasant".

Do you think that LT system gives pleasant or unpleasant heat?



Do you think that LT system gives an improvement of the indoor climate or not?



Evaluation of indoor climate

Occupants were asked their opinion about the indoor climate in terms whether or not it was improved compared to their previous dwelling. Notable, again, was the very positive score for floor and wall heating (>70%). 61% of the occupants with LT radiators did not notice any difference.

Controllability of heating systems

Floor and wall heating are often regarded as systems with a slow reaction time. However, modern systems seem to react much faster. For this reason occupants were asked about their experiences with the heating up time after a longer period of absence. The majority of the occupants with floor heating (55%) and wall heating (65%) indicate that the heating system does not heat up the dwelling very fast. 68 % of the occupants with LT radiators indicate a fast heating up time. However, these scores don't seem to have an influence on the satisfaction considering the controllability of the temperature. A minority indicates to be dissatisfied with the controllability of their heating system with no significant difference between floor heating (10%) and wall heating (12%) and a little better score for LT radiators (5%).

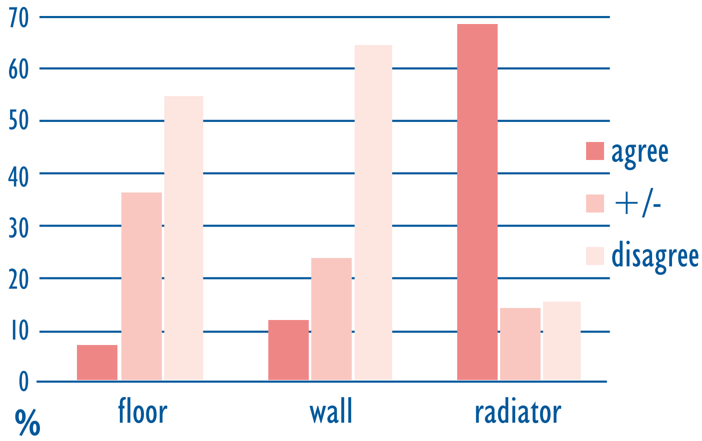
Satisfaction with different LT systems

Occupants with LT radiators are less satisfied with their system than occupants with the other two systems. Results concerning satisfaction of wall heating and floor heating don't show significant differences; 70 % of the occupants are satisfied with their system. The evaluation of the LT heating emission system and the total heating system (including heating source) are very much related.

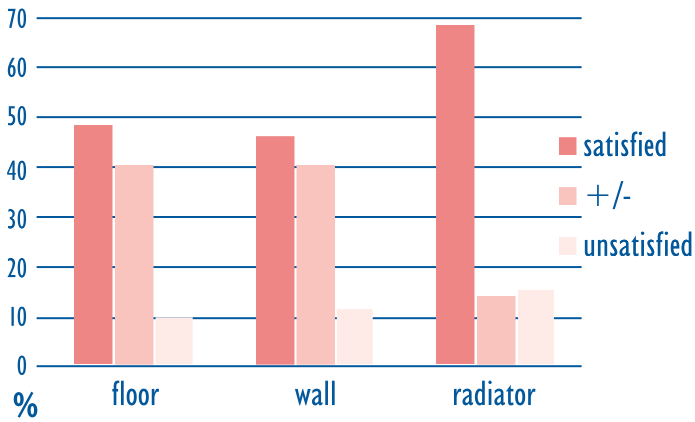
Relation between evaluation of heating and evaluation of DHW and ventilation system

The assessment of different building services systems in a dwelling can be strongly influenced by the bad functioning of only one of the systems. Also a very high appreciation of one of the parts can also mask problems with other parts of the system. The relation is analysed between the heating system, DHW system and ventilation system. This evaluation shows that the assessment of the DHW system is not related to the assessment of the heating or the ventilation system. The assessment of the ventilation system is however correlated to the heating system. Occupants who are satisfied with the function of the heating system are also satisfied with their ventilation system and visa versa.

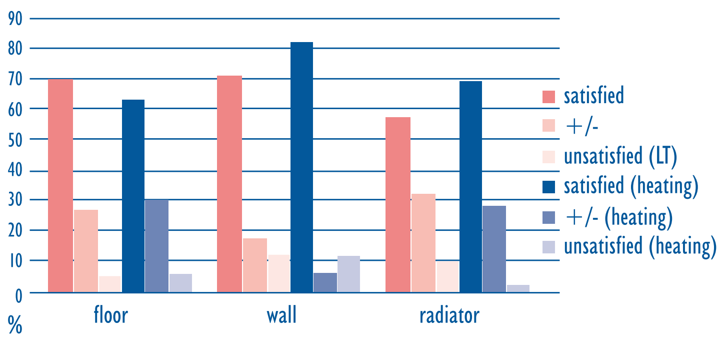
Dwelling heats up fast after long period of absence.



Satisfaction with the controllability of the temperature.



Satisfaction with LT heating system /heating in general.



CONCLUSIONS

Results of this survey can not be generalised for the total Dutch new building stock. All these projects concern demonstration projects for LT systems.

Occupants did not select their dwellings primarily because of environmental reasons. However, for 58 % of the occupants the environmental aspect was an important in the final selection of their dwelling. Floor heating is an important decision factor for the selection but not as a particular energy or environmental measure. Therefore it is recommended to give more information and to communicate about the energy efficiency of LT systems.

A majority of the occupants with LT radiators don't have any idea that they have a LT system. On one hand this is positive because there seems to be no difference (disadvantage) in comparison with more conventional systems, on the other hand it could be recommended to communicate about the energy efficiency of these systems.

Occupants with floor and wall heating apply a small temperature difference for night set back. Occupants would be interested to get instructions for how to use their heating appliances to reach an optimum between energy use and thermal comfort. About 50% of the occupants do not use heating in bedrooms during wintertime.

The advantages and disadvantages, mentioned by the occupants in this survey match the results of previous researches. This survey also confirms the results of the literature review on side effects of low exergy emission systems (IEA Annex 37 report). Especially the reaction of the occupants about the perception of indoor air quality, thermal comfort, slowness and lack of controllability of some LT systems confirm previous studies.

Although LT systems are very well accepted and appreciated, there are some negative aspects and disadvantages that could be taken into account and be solved. These are for example the controllability per room (floor and wall heating) and sizes, design and installing of LT radiators.

All LT systems are very well received. Particularly indoor climate is much improved in dwellings with floor and wall heating compared to previous situations. For LT radiators the occupants found no difference in the indoor climate compared to their previous situation. The main disadvantage is the controllability, especially with floor and wall heating; 30 to 40% of the occupants mention poor controllability as a disadvantage.

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The exergy-entropy process of any working system consists of the following four fundamental steps. The systems first feed on exergy and then consume its portion or its whole to perform their purposes, while at the same time producing entropy as the result of exergy consumption, and finally they discard the produced entropy into the environment. The disposal of the produced entropy enables the systems to feed on exergy again. Thus the cyclic operation of these four steps is indispensable for the systems to keep working. Such exergy-entropy process applies to the human body, which occupies the built environment controlled by heating and cooling systems.

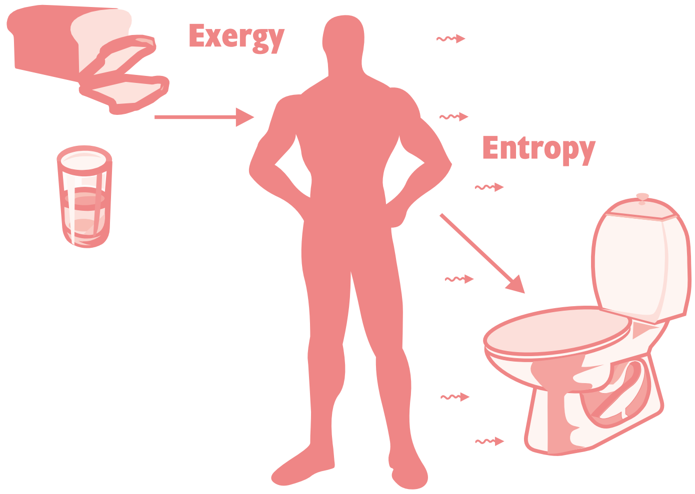

Figure 1. The human body works as an exergy-entropy process.

EXERGY-ENTROPY PROCESSES IN BUILT ENVIRONMENT

We humans feed on exergy contained by food, and thereby consume it within our body so that we can sense, think and perform any physical work contracting our muscles. In due course, we inevitably produce entropy and it must be discarded into the built environment.

Heating and cooling systems for buildings, whether they are active or passive, also work as exergy-entropy process. This is what thermodynamics tells us. "Exergy" is the concept to articulate what is consumed within a system and "entropy" is what is disposed of as waste from the system. Stated in the other way, exergy is the concept that quantifies the ability of energy and matter to disperse, and entropy is the concept that quantifies how much dispersed the energy and matter are.

EXERGY BALANCE

It is vitally important to have a clear image of the exergy balance of human body in order to understand what the low exergy systems for heating and cooling of buildings are. Therefore we have developed a mathematical model of the human exergy balance and made its numerical calculation and related the result to human thermal sensation. The general form of exergy balance equation of a system is described as follows

Input Exergy - Exergy Consumption = Stored Exergy + Output Exergy

In the case of human body, "input exergy" is warm exergy and wet exergy generated by the metabolism. "Warm" exergy is a portion of the sensible heat, which is the ability to diffuse, and "wet" exergy is the ability of liquid water to disperse into the environmental space by evaporation. Both warm and wet exergies are provided by the metabolic chemical reactions occurring within the human body.

"Exergy consumption", the second term of the above equation, occurs to maintain the body temperature as constant as possible. The difference between the input exergy and the exergy consumption becomes either stored exergy or output exergy shown in the right-hand side of the above equation.

The actual exergy balance equation to be calculated has been developed combining the energy, mass, and entropy balance equations set up for both the core and the shell of the human body.

EXAPMLE

Figure 2 shows one of the results of our numerical calculation assuming a set of thermally steady-state environmental conditions: the relationship between the input warm exergy, the input wet exergy, the exergy consumption rate, and the environmental temperature with the corresponding thermal sensation, PMV*. The assumptions we made for calculation are the environmental temperature equal to the ambient air temperature and the mean radiant temperature, the air movement of 0.1 m/s, the clothing insulation of 0.6 clo (= 0.093 m^2K/W), and the metabolic energy rate of 1.1 met (= 64 W/m^2).

The higher the environmental temperature is, the lower the total input exergy is.

EXERGY FOR THERMAL COMFORT...

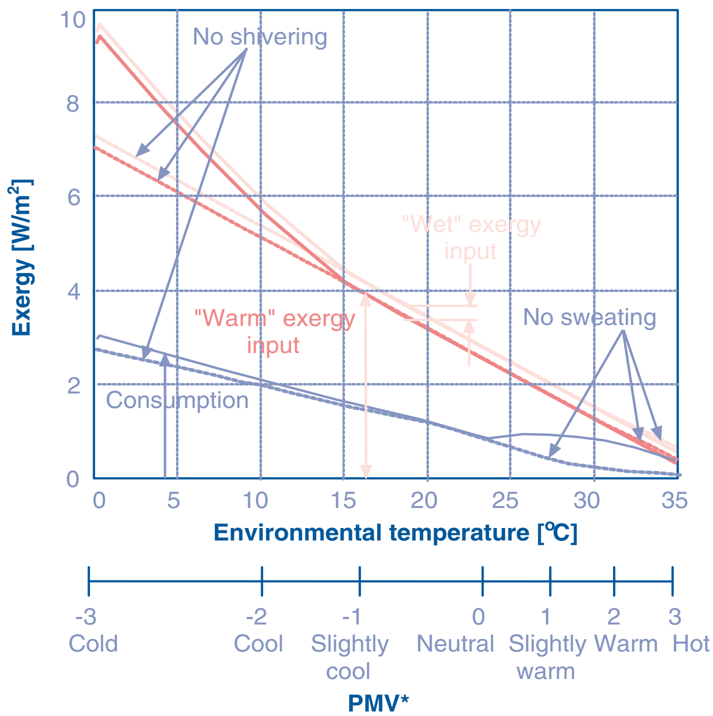

Figure 2. Exergy input and exergy consumption within human body (Watt per unit body-surface area, W/m²) versus environmental temperature (°C).

The exergy consumption rate within the human body also becomes smaller as the environmental temperature becomes higher under the conditions from cold to neutral. It becomes the lowest at neutral. Dotted lines appearing between 0°C and 15°C correspond to the case that no shivering is assumed. The difference in the input exergy between the cases with and without shivering is “warm” exergy generated for maintaining the body temperature constant by shivering. This warm exergy, which is produced by chemical exergy consumption within the muscle cells, is larger as the environmental temperature gets lower. Nevertheless, the exergy consumption rate, which is used for keeping the body temperature constant, varies little even though no shivering is assumed.

The exergy consumption rate becomes slightly larger as the environmental condition changes from neutral to slightly warm. Under the environmental conditions from neutral to hot, the maximum exergy consumption rate occurs near slightly warm. Dotted lines appearing between 23.5°C and 35°C correspond to the case that no sweating is assumed. The skin temperature would become higher if there was no sweating and hence the difference in temperature between the core and the shell would become smaller. This would result in smaller exergy consumption rate. Consequently, the difference in exergy consumption rate indicated by the solid and dotted lines is considered to contribute to lowering the skin temperature by sweating.

It is interesting that the thermal comfort, the thermally neutral condition, is provided with the lowest exergy consumption rate as far as the conditions from slightly cool to slightly warm are concerned.

The next step of this research is to investigate how such a pattern of the human-body exergy consumption relates to the exergy balance of various heating and cooling systems and find out what the low exergy systems are.

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ANNEX 37 WEBSITE

HTTP://WWW.VTT.FI/RTE/PROJECTS/ANNEX37/

All the information about Annex 37 will be found on our website. It is updated continuously. There you can find the

- Status Reports
- information about the meetings and publications
- contact information
- links to other useful sites etc.

NEXT MEETINGS OF ANNEX 37

3rd Expert Meeting
The Third Expert Meeting of Annex 37 will be held on 26th to 27th March 2001 in Hamburg, Germany.

4th Expert Meeting
The 4th Expert Meeting will be held on 13th to 14th September 2001 in Rome, Italy.

5th Expert Meeting
The 5th Expert Meeting will be held in Mid-May 2002.

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Annex 37

LOW EXERGY SYSTEMS FOR HEATING AND COOLING OF BUILDINGS

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