LowEx

EXERGY ANALYSIS

HUMAN BODY EXERGY CONSUMPTION AND THERMAL COMFORT

Participants in the meeting (from the left): Masanori Shukuya, Koichi Isawa, Paul Ramsak (sitting), Per Gundersen, Mrs. Gundersen (visiting), Dietrich Schmidt, Giorgio Giorgiantoni, Markku J. Virtanen, Åsa Nystedt, Johann Zirngibl, Claude François and Peter Op ´t Veld.

The fifth expert meeting was held in Sophia-Antipolis 23–25 april 2002. Participants from France, Italy, The Netherlands, Japan, Norway, Sweden and Finland attended the meeting.

THE FIFTH EXPERT MEETING

The meeting was very productive and many important decisions were made. An exergy analysis tool seems to be in good developing progress and the system concepts to be further analysed were chosen. We also heard some very interesting technical presentations. One was about LowEx systems in retrofits in Norway that may be introduced in the next issue of LowEx news. The other presentation was about "Human-body exergy consumption varying with the combination of room air temperature and mean radiant temperature".

There is an article about this issue in this LowEx news. A workshop about LowEx systems in existing buildings was held. There was a presentation about cases from Slovenia, Greece and The Netherlands. A short analysis about the market for low temperature heating systems in retrofit was made for all the countries present. In the next meeting a follow up workshop will be held and the next issue of LowEx news will be about low temperature heating systems in existing buildings. An action list was made with many actions to be done before the next expert meeting in Oslo.

Åsa Nystedt, VTT, Finland

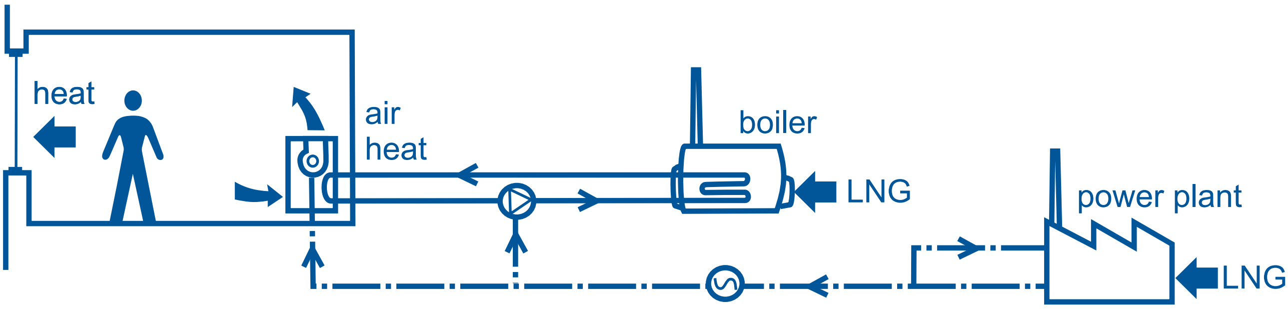

Figure 1. A space heating system assumed for example calculation of exergy consumption.

Any heating and cooling systems feed on exergy, thereby consume its portion and generate corresponding entropy accordingly, and finally discard the generated entropy. This is one cycle of "exergy-entropy process" performed by the systems. Numerical analysis of various heating and cooling systems with respect to exergy consumption can provide us with a better picture of what really happens within the systems during their courses of exergy-entropy process. Here we explain an example of exergy analysis of a space heating system.

Let us compare three numerical examples of exergy consumption during the whole process of space heating from the power plant, through the boiler to the building envelope in the steady state as shown in Figure 1. Case 1 assumes that the thermal insulation of the building envelope system is poor; that is, single window glazing and an exterior wall with only a thin insulation board, and a boiler with a moderate thermal efficiency. Case 2 meanwhile assumes that the thermal insulation of the building envelope is improved by a combination of double window glazing and an exterior wall with improved insulation, while the boiler efficiency remains unchanged. Case 3 assumes in addition that the boiler efficiency is improved to near its limit. Table 1 summarizes the assumptions for calculation in three Cases.

Figure 2 shows respective three series of exergy input, exergy consumption, and exergy output from the boiler, to the water-to-air heat exchanger, to the room air, and finally to the building envelope in three Cases.

Exergy consumption is the difference in exergy between input and output; for example, in Case 1, 2554 W of exergy is supplied to the boiler and 420 W of "warm" exergy is produced and delivered to the heat exchanger by hot water circulation so that their difference, namely 2134 W (=2554-420), is consumed inside the boiler. The same explanation applies to all of other sub-systems.

Exergy consumption within the boiler is the largest among the sub-systems. Consuming a lot of exergy is unavoidable when extracting thermal exergy by a combustion process from the chemical exergy contained in LNG. Because of this, one may consider that the improvement of boiler efficiency is essential. The dashed line indicated below Case 1 shows the result of the improvement of boiler efficiency from 0.8 to 0.95 in Case 1. The decrease of exergy consumption is marginal. One may, then, consider that increasing the outlet water temperature of the boiler makes exergy output from the boiler larger and hence the boiler more efficient. This, however, results in the consumption of more exergy within the water-to-air heat exchanger and also within the room air, in which the required temperature is 293 K (20°C). These facts imply that an extremely high boiler efficiency alone cannot necessarily make a significant contribution to reducing exergy consumption in a whole process of space heating.

The heating exergy load, which is the exergy output from the room air and the exergy input to the building envelope is 148 W in Case 1 and 78 W in Case 2 and 3. It is only 6 to 7% of the chemical exergy input to the boiler so that one may regard a measure reducing the heating exergy load as marginal. But, as can be seen from the difference in the whole exergy consumption profile between Case 1 and Case 2, it is more beneficial to reduce the heating exergy load by installing thermally well-insulated glazing and exterior walls than to develop a boiler with an

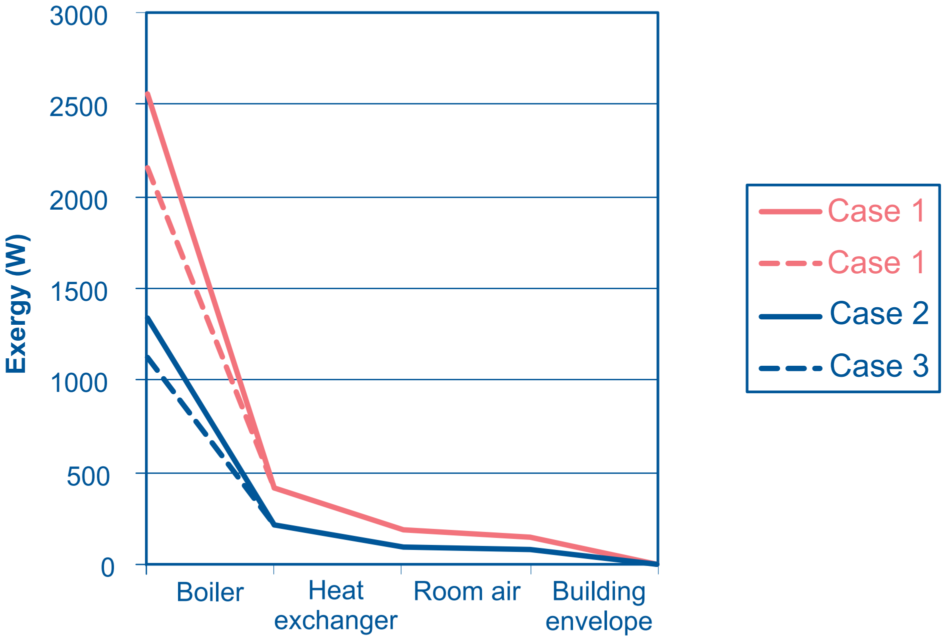

Figure 2. A comparison of exergy consumption for four stages of the space heating systems. Exergy consumption is the difference in exergy between input and output; for example, in Case 1, 2554 W of exergy is supplied to the boiler and 420 W of "warm" exergy is produced and delivered to the heat exchanger by hot water circulation so that their difference, namely 2134 W (=2554-420), is consumed inside the boiler.

Assumptions for example calculation of exergy consumption

CASE	Heat loss coefficient of building envelope		Thermal efficiency of boiler
1	108.7 W/K	(3.0 W/(m²·K))	80 %
2	57.1	(1.59)	80
3	57.1	(1.59)	95

Heat-loss-coefficient values in the brackets are those per unit floor area. A 6.0m x 6.0m x 3.0m room with one exterior wall having a 1.5m x 6m glazed window is assumed. The exterior-window and -wall U values are 6.2 and 2.67 W/(m²·K) for Case 1; 3.6 and 1.14 for Cases 2 and 3. The number of air changes due to infiltration is 0.8 h-1 for Case 1; and 0.4 h-1 for Cases 2 and 3. The room air temperature is ideally controlled and kept constant at 293 K (20°C) in all cases while the outdoor air temperature is assumed to be constant at 273 K (0 °C). Outlet air temperature, inlet and outlet water temperatures of the heat exchanger are assumed to be 303 K (30°C), 343 K (70°C), and 333 K (60°C), respectively, for all Cases. The rates of electric power supplied to a fan and a pump are 30 W and 23 W in Case 1; 16 W and 12 W in Cases 2 and 3. The ratio of the chemical exergy to the higher heating value of liquidified natural gas (LNG) is 0.94. The thermal efficiency of the power plant, that is, the ratio of produced electricity to the higher heating value of LNG supplied is 0.35.

extremely-high thermal efficiency, in order to decrease the rate of total exergy consumption.

The reduction in exergy consumption of the boiler sub-system indicated by the difference between Case 2 and Case 3 due to the improvement in boiler efficiency turns essentially meaningful together with the improvement of building-envelope thermal insulation.

Previous technology development has had a tendency, for example, that the development of mechanical equipment such as heat pumps, boilers and others proceeds rather independently from the development of advanced building envelope systems. The above example of exergy calculation strongly suggests that both of the developments must be made in a consistent manner with each other. We could then realize truly low exergy systems for heating and cooling of buildings. ■

Masanori Shukuya,
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EXERGY ANALYSIS TOOL UNDER DEVELOPMENT

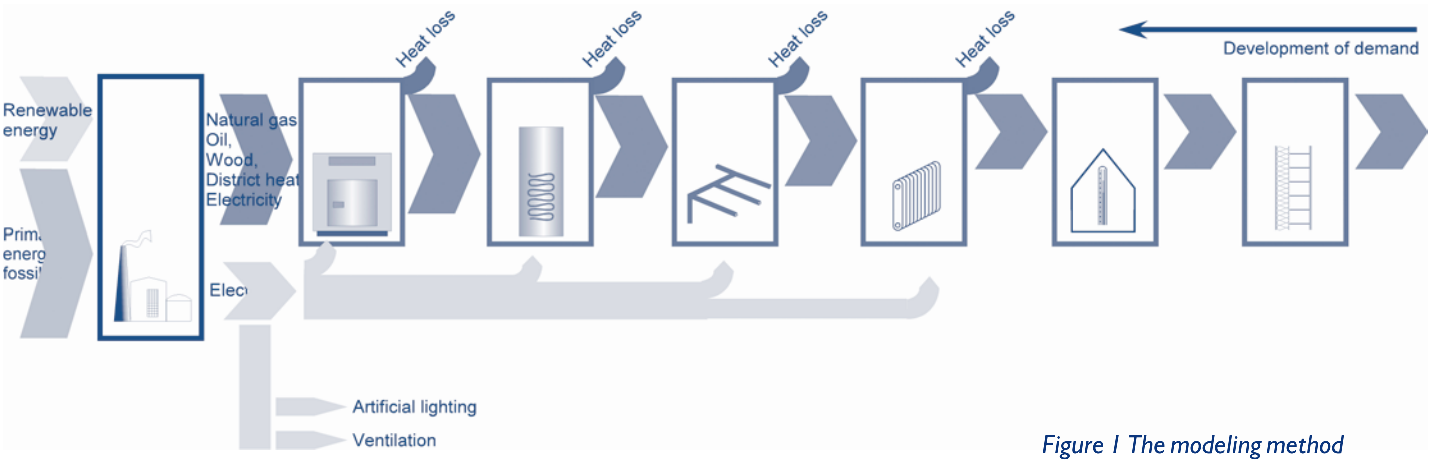

Figure 1 The modeling method

How could we easily analyse cases like the one presented in the previous article? An easy to understand exergy analysis tool for pre-design purpose is within the scope of the Annex 37 currently under development. It will enhance our understanding about exergy flows in buildings and provide us with similar information as shown in the previous case. The tool will be finished by the end of year 2002.

To understand exergy flows in buildings it is important to know, how much and in which part of the system exergy is lost. In that way we will gain a better knowledge of where it is efficient to put in efforts to optimise the system exergetically. The results of the exergy analysis will be given in the same format as figure 2 from the previous article, where some suggestions on how to increase exergy efficiency in heated buildings are given. It is most important to reduce the heat losses, i.e. the exergy load on the system.

AUXILIARY ENERGY WILL ALSO BE INCLUDED

The scope for the analysis tool is wider than the analysis shown above. The input and calculation procedures are more sophisticated. So the required input on free available renewable energy and fossil primary energy will be computed separately and the components described with specific heat losses and needed auxiliary energy. In this way the electricity needed for the different building services appliances (like pumps, fan and control devices) is taken into account. This is especially important from an exergy point of view, since electricity is a high exergetic energy source.

To complete the entire energy chain in a building (from the energy source to the heat sink), the systems shown in the case above (heat generation, emission, room and envelope) are added with heat storages and the different possibilities of heat distribution systems. Compare with figure 1 and figure 1 in the previous article. Thus, the calculation procedures of the Annex 37 tool correspond to the ones used for a number of new European energy codes, like the German EnEV, established in early 2002.

The calculation is based on steady state energy flow consideration for typical design conditions for heating or cooling. Than losses and exergy flows are computed in the direction of the development of demand, as shown in figure 1 in this article.

The evaluated results from the building analysis are compiled into exergy-energy flow diagrams, similar to figure 2 in the previous article and the entire calculation procedure will be clearly reported on just two A4 pages. If desired, Sankey-diagrams (flow diagrams) could be generated with this output data for an increased comprehension.

DEMONSTRATION PROJECTS WILL BE ANALYSED

A number of demonstration projects from all participating countries of the Annex 37 will be analysed in this way to show the possibilities for exergy analysis and optimisation in buildings. The results will be published in the final report of the Annex, the guidebook. ■

Dietrich Schmidt, KTH, Sweden

HUMAN-BODY EXERGY CONSUMPTION AND THERMAL COMFORT

According to our previous research, see for example "THE HUMAN BODY CONSUMES EXERGY FOR THERMAL COMFORT" by Masaya SAITO and Masanori SHUKUYA, LOW-EX NEWS No.2, the lowest human-body exergy consumption occurs at thermally neutral condition. Exergy consumption within the human-body becomes higher in cold environment due to larger difference in temperature between the human body and its surrounding space and also becomes higher in hot environment due mainly to sweating. These findings have suggested that heating and cooling systems may also work well at such a condition that the lowest amount of exergy is consumed by those systems. That is, we may be able to establish both thermal comfort and low-exergy consuming systems at the same time.

Our further research on human-body exergy balance has just come onto a new stage, where it becomes possible for us to calculate more realistic cases than before, such that the environmental temperature for exergy calculation need not be presumed to be equal to the average of indoor air temperature and mean radiant temperature. What follows is a piece of our new findings, which enhances our previous finding.

Figure 1 shows a new relationship between human-body exergy consumption, thermal comfort (PMV*=0), room air temperature, and mean radiant temperature. The assumptions made for this calculation are outdoor air temperature and relative humidity of 0 °C and 50 %, a typical winter condition in Tokyo-Yokohama area; indoor air current and relative humidity of 0.1 m/s and 40 %; a typical winter clothing (0.9clo); and a metabolic thermal-energy generation rate at an ordinary office work (1.1met).

As can be seen, the human-body exergy consumption rates vary with the combinations of room air temperature and mean radiant temperature. The solid line corresponds to thermally neutral conditions, to which most people feel thermally comfortable. The area below the line corresponds to rather cold environment. The lower either room air temperature or mean radiant temperature is, the higher the human-body exergy consumption rate is. The reason is that the difference in temperature between the clothing surface and room air and interior wall surfaces becomes large. On the other hand, the area above the line corresponds to rather hot environment. The higher either room air temperature or mean radiant temperature is, the slightly higher the human-

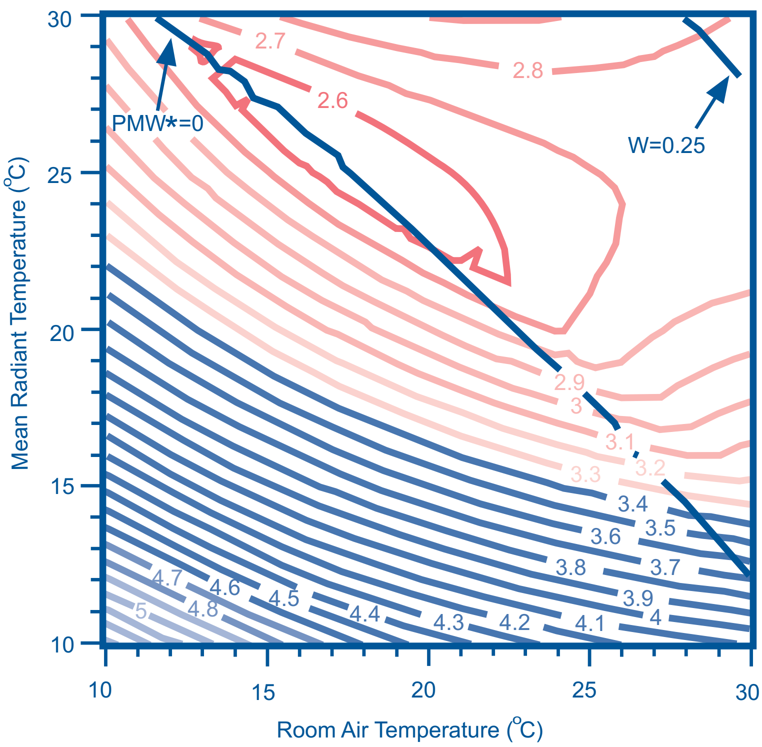

Figure 1 The relationship between exergy consumption within the human-body (W/m2), room air temperature, and mean radiant temperature. A solid line going down from upper left to lower right indicates thermally neutral condition (PMV=0); this is based on 'energy' balance calculation. A broken line appearing at upper right is skin wetted-ness, up to which most people could tolerate. There is the optimal combination of room air and mean radiant temperatures, which gives the lowest exergy consumption and thermal comfort.*

body exergy consumption is. This is because sweating occurs and evaporation takes place and thereby the difference in temperature between the skin and room air and interior wall surfaces becomes large. A broken line appearing at upper right corresponds to the condition of skin wetted-ness, up to which most people could tolerate.

The lowest exergy consumption rate emerges at the point, where the room air temperature equals 18 °C and mean radiant temperature 25 °C. This suggests that the use of radiant warm exergy is more effective than the use of convective warm exergy for a heating purpose to realize both thermal comfort and as low exergy consumption within the human-body as possible.

Such a built environment can be provided by a moderate radiant heating system combined with passive heating strategies, for example, good thermal insulation and suitable thermal-exergy storage capacity of building envelopes, solar-thermal-exergy gain through properly-insulated window glazing and others.

It is interesting to see that, from the exergetic view point, there is the optimal combination of room air temperature and mean radiant temperature, which gives thermally neutral condition, namely PMV*=0, although, from the conventional energetic viewpoint, there are many combinations of room air temperature and mean radiant temperature. Some of the experienced scientists and engineers say that what they can see in Figure 1 is consistent with their experiences. It would be very encouraging for architects and engineers to conceive a system with as low-exergy consumption as possible, since it would bring about a higher quality of warmness that the occupants can sense in their given built environment.

The human-body exergy analyses have now just started to articulate why Low-Exergy Systems are essential for creating rational and comfortable built environment.

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ANNEX 37 WEBSITE

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

On Annex 37 website we have collected information about Annex 37: background, objectives and working methods as well as information on participants, meetings and publications. The website is updated continuously, so the latest information will always be found on the website. There you can find the

- Contact information
- Status reports
- Previous issues of LowEx News (in pdf format)
- Technical Presentations about Annex 37 issues in ECBCS ExCo meetings
- Links to other useful sites

FOLLOWING NEWSLETTERS

LowEx News nr 6

The next issue of LowEx News will be about low temperature heating systems in existing buildings. We will present a review about the situation in different countries concerning this issue. Some cases will be presented and some technical concept suitable for retrofits will be presented. There will also be a few words about limitations and opportunities for LowEx systems in retrofits.

LowEx News nr 7

The Newsletter nr 7 will include technical presentations of different system concepts.

NEXT MEETINGS OF ANNEX 37

Sixth Expert Meeting

Sixth Expert Meeting will be held on 26th to 28th September 2002 in Oslo, Norway. Sustainable Building conference will take place in Oslo on 23rd to 25th September.

Seventh Expert meeting

Seventh Expert meeting will be held in April 2003 in Japan.

Final Meeting

The Final Meeting of Annex 37 will be held in October-November 2003 in Finland.

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Annex 37

LOW EXERGY SYSTEMS FOR HEATING AND COOLING OF BUILDINGS

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