Energy Efficiency Measures: In Different Climates and in Architectural Competitions

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Abstract Energy use of buildings is strongly affected by the climate the building is located. Some measures are effective in all climates, but attention to energy balance components and proper solutions depends on climate. An office building case study is used to show the performance in all climates, temperate, Mediterranean, cold and tropical described with Paris, Rome, Stockholm and Bombay weather data. It is shown that energy performance can be strongly improved with energy-efficient building envelope elements especially for windows and solar shading, modern lighting system with intelligent controls and optimal HVAC system with very efficient heat recovery, good chiller design and a high-temperature room-conditioning application. When building is located in Mediterranean or tropical climate conditions, significant part of energy use comes from cooling/drying of supply air, stressing the importance of corresponding solutions. Energy efficiency measures are evidently important design issues, to be tackled already in very early stages with integrated design. This applies also for architectural competitions. The problem is that if energy performance targets will be applied after architectural competition, this might be too late, and in worst case, the whole proposal has to be redesigned to meet the targets. To avoid such problems, energy performance targets are to be included in the competition brief among all other targets. It is discussed how energy performance targets can be included so that they will lead to integrated design from very first steps, but unnecessarily, complicated and detailed analyses can be avoided. Two possible approaches, one based on simple indirect indicators requiring a minimum calculation effort and another based on energy simulations, are discussed. A case study example with the application of the second approach is reported.

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1 Energy Efficiency Measures in Different Climates

1.1 Technical Solutions and the Office Building Studied

To evaluate the energy efficiency and the energy-saving potential, three different kinds of buildings were used with same floor plan and window sizes (see Fig. 1). Basic reference building has structures, which has been typically used in Central European climate conditions and according to the local regulations for new buildings [1]. In advanced building, thermal conductivity of external structures has been improved as well as solar shading of window and lighting system. In low-energy building, the structures were the same as in the advanced building case, but lighting system was still improved. Energy simulations were done with IDA-ICE 4.0 tool by calculating the annual energy need of the office building. The simulation tool is validated according the International Energy Agency's validation exercises [2].

1.2 Basic Reference Building

Selection of indoor temperatures and ventilation rates were based on EN 15251 [5]. Energy-efficient heating, ventilation and air-conditioning (HVAC) systems were simulated for room air-conditioning and ventilation [3, 4]. The basic reference building was simulated with dedicated outdoor air system (DOAS), active chilled beams (with constant air volume) and fan coils where supply air and water were used for cooling/heating, and with variable air volume (VAV) system where only

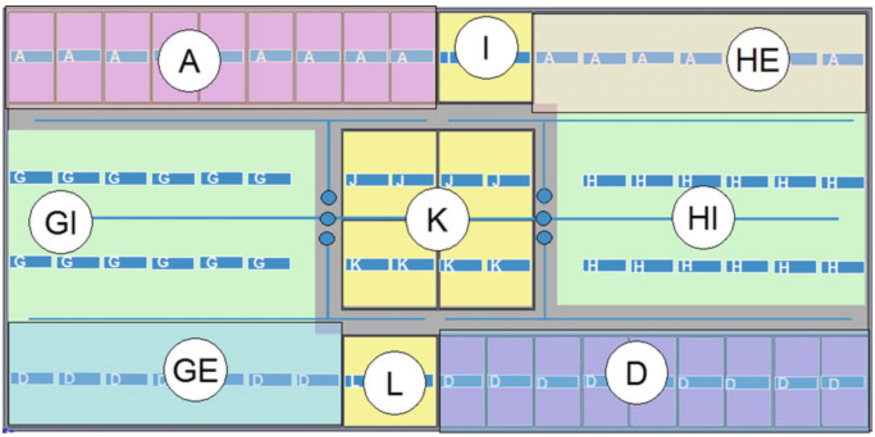

Fig. 1 Floor plan of the building and division to several operational zones: office rooms (*A*, *D*), landscape offices (*H*, *G*) and meeting rooms (*I*, *K*, *L*)

supply air was used for cooling/heating. Active chilled beams were selected for HVAC system in the basic reference building because of their lowest energy and electricity use. With fan-coil system, the fan efficiency of individual fans in the room units causes the bigger energy use, and with VAV system, the use of air as the media for cooling/heating power makes it less energy efficient in common office spaces where required supply air volume is not big. Cooling water for the air handling unit (AHU) and chilled beams was cooled by using one chiller system where the coefficient of performance (COP) was calculated with model taking into account part load ratios and outside air temperature of real chiller.

1.3 Advanced Building

For advanced building, chilled beam system was changed to more energy-efficient adaptable active chilled beams with VAV function for meeting room based on CO_2 concentration of room air. Also other HVAC system features were changed, like efficiency of heat recovery system and chiller design. Two chillers were used in advanced and low-energy buildings in order to get higher COP from the high-temperature cooling of chilled beam system and handle the AHU low-temperature cooling with other chiller. There was also added free cooling circuit so that the capacity of outside air temperature is used for cooling when possible. The chilled ceiling system (water circulated) was also simulated in the advanced building case in order to find out whether better energy efficiency could be achieved. The HVAC system selection for advanced building was still adaptable chilled beams, because the energy use was nearly the same with these systems, and for calculating the cases in different climate conditions, chilled beam system can provide more cooling power more flexibly.

1.4 Low-Energy Office Building

For low-energy office building case, the same chilled beam system was used as in advanced building case, but there was lower pressure level in the ventilation system. Also heat recovery was changed to a yet more efficient rotating wheel and lighting system to LED-based lighting with occupancy control.

1.5 Common Features of the Office Building Case

The simulation was made using 11,000-m^2 office building (10 floors), each floor with a mixture of different types of spaces: landscape offices 610 m^2 (55 %), office rooms 242 m^2 (22 %), meeting rooms 162 m^2 (15 %) and other (rest rooms, etc.)

Table 1 The heat load levels and schedules for occupancy, equipment, lighting and ventilation

	Basic reference building	Advanced building	Low-energy building
Occupants	Mo–Fri 8–18	Mo–Fri 8–18	Mo–Fri 8–18
Maximum number of occupants, m^2/person	10 (office), 15 (landscape), 2 (meeting room)	10 (office), 15 (landscape), 2 (meeting room)	10 (office), 15 (landscape), 2 (meeting room)
Average occupancy in offices, %	57.5	57.5	57.5
Average occupancy in meeting rooms, %	28.6	28.6	28.6
Equipment	Mo–Fri 8–18	Mo–Fri 8–18	Mo–Fri 8–18
Maximum equipment load, W/m^2	20 (office), 15 (landscape), 30 (meeting room)	20 (office), 15 (landscape), 30 (meeting room)	20 (office), 15 (landscape), 30 (meeting room)
Average equipment load ratio, %	Same as occupancy	Same as occupancy	Same as occupancy
Lighting	Mo–Fri 7–20	Mo–Fri 7–20	Mo–Fri 7–18
Lighting load, W/m^2	15	12	6
Control principle	Time	Time + daylight	Daylight + occupancy
Ventilation	Mo–Fri 7–19	Mo–Fri 7–19	Mo–Fri 7–19

95 m^2 (8 %). The main facades were towards north-west and south-east. Window height was 1.8 m and width 1.2 m, one window in each 1.35 m module, so window–floor ratio was 25 % in external offices. The heat load levels and schedules for occupancy, equipment, lighting and ventilation are presented in Table 1. They were typical for usual office building. Other building and system design parameters are presented in Table 2. Energy simulation was made using Paris–Orly weather data in all basic reference, advanced and low-energy cases. Then, the low-energy case was also simulated then with Stockholm, Rome and Bombay weather data to analyse the situation more comprehensively.

1.6 Energy Use

The total energy use and division for cooling, heating, ventilation fan energy, pumping and lighting are shown in the Fig. 2 as energy delivered to the building and in Fig. 3 as primary energy where gas for heating and electricity is weighted according to the efficiency of the energy production. Usual values for the primary energy factors have been used: 1 for gas and 2.5 for electricity.

The annual delivered energy use of the low-energy building, the most energy-efficient office building, in middle European climate is 22 kWh/m^2 and the primary energy use is 49 kWh/m^2. In the advanced building, the building with most common energy-efficient features, both delivered energy and primary energy uses are two times higher, and in the basic reference building with good standard construction, both uses are almost four times.

Table 2 Design values of reference, advanced and low-energy building

	Basic reference building	Advanced building	Low-energy building
External wall W/K, m^2	0.43	0.3	0.3
Infiltration L/s, m^2	0.33	0.165	0.165
Window W/K, m^2	2.6	1.1	1.1
Window g-value	0.48	0.31	
Solar shading	No	External overhang of 500 mm	External overhang of 500 mm
Room terminal unit	Traditional active chilled beam	Adaptable active chilled beam	Adaptable active chilled beam
Chiller plant with air cooled condensers	One common chiller (2 °C)	2 chillers: beams (10 °C), AHU (2 °C)	2 chillers: beams (10 °C), AHU (2 °C)
Room unit inlet water temperature	15 °C	15 °C	15 °C
Room control	P	PI	PI
Room temperature set value	20.5/24 °C	20.5/25 °C	20.5/25 °C
Boiler plant	Condensing boiler	Condensing boiler	Condensing boiler
Airflow rates	DOAS: 1.5 L/s, m^2 in offices, 4.2 L/s, m^2 in meeting rooms	DOAS: 1.5 L/s, m^2 in offices, 4.2 L/s, m^2 in meeting rooms	DOAS: 1.5 L/s, m^2 in offices, 4.2 L/s, m^2 in meeting rooms
Airflow design	CAV in all spaces	CAV in offices, VAV in meeting rooms	CAV in offices, VAV in meeting rooms
Ductwork	Balanced	Constant pressure	Constant pressure
SFP kW/m^3, s	2.0	1.8	1.2
AHU cooling water temperature	7 °C	7 °C	7 °C
Supply air temperature	16 °C (External $T > 20$ °C) 20 °C (External $T < 10$ °C)	16 °C (External $T > 20$ °C) 20 °C (External $T < 10$ °C)	16 °C (External $T > 20$ °C) 20 °C (External $T < 10$ °C)
Heat recovery	Hydronic (40 %)	Plate (60 %)	Wheel (80 %)
Filtration	EU7 in supply and EU3 in exhaust	EU7 in supply and EU3 in exhaust	EU7 in supply and EU3 in exhaust
Night purge ventilation	No	Yes	Yes

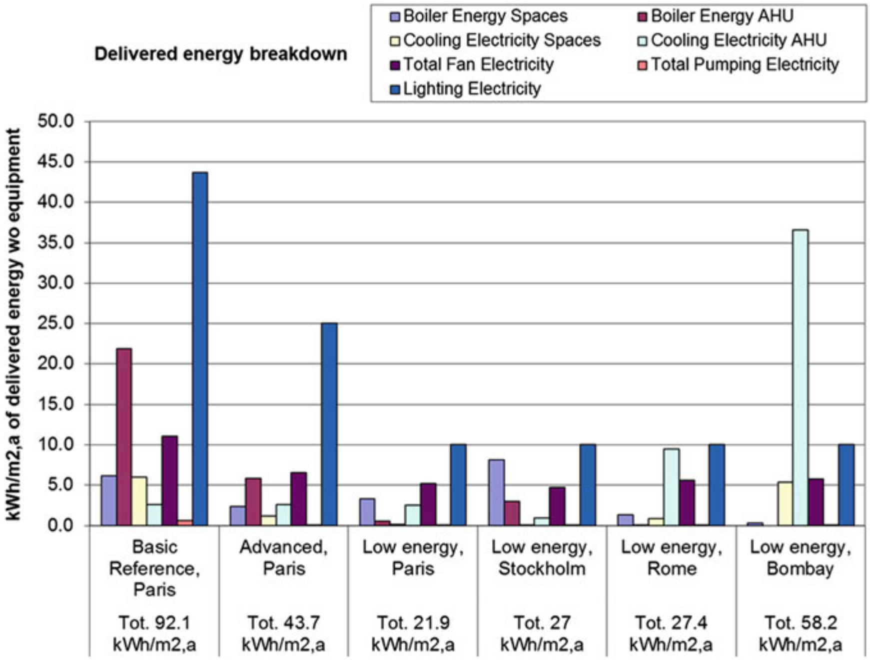

Fig. 2 Delivered energy use in different cases

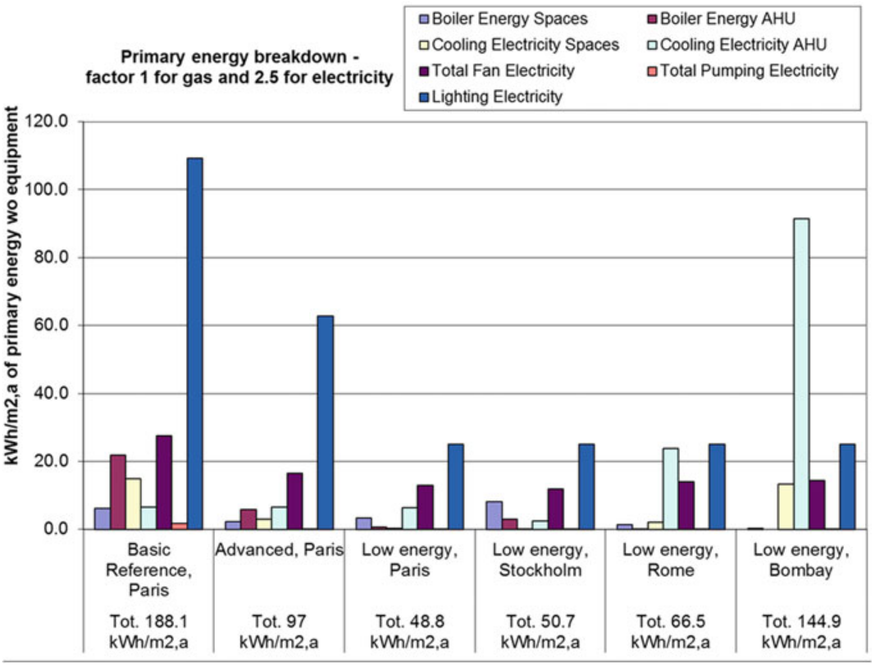

Fig. 3 Primary energy use in different cases

The biggest primary energy consumer is lighting, in the standard building four times bigger than second consumer and in the most efficient building in Paris two times. The second biggest is fan energy in these buildings. Heating and cooling energy demand is very small in the most efficient building. The cooling and heating energy breakdown is shown in the Figs. 4 and 5. The biggest reason for that is the efficient solar shading and very efficient heat recovery in AHU, which reduces significant amount of heating energy especially in the case of Nordic climate, and cooling energy in the case of Mediterranean and tropical climate.

Energy-efficient lighting system in the advanced and especially in low-energy buildings also lowers the internal heat load level so that the effect to the cooling energy use remains small. The primary energy for cooling and drying of ventilation supply air is the second biggest consumer in Mediterranean and clearly biggest in tropical climate.

The comparison of energy use in the office building with standard, advanced and low-energy constructions in different climate conditions opened following items for discussion:

- Lighting is the biggest energy consumer, only in the tropical environment cooling/drying of supply air is bigger; there are solutions for making lighting more energy efficient as seen in this comparison, but new solutions for supply air cooling/drying would be needed especially in tropical climate.

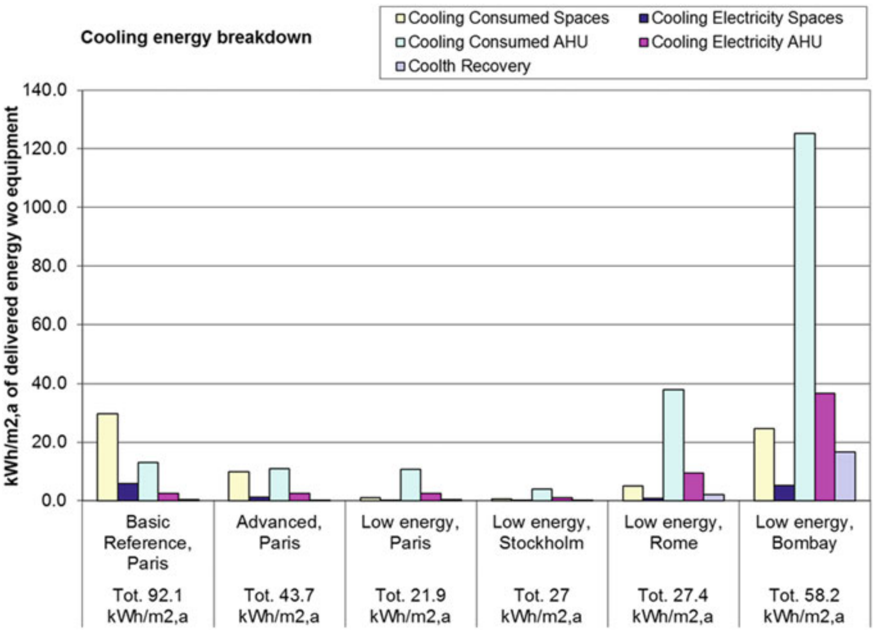

Fig. 4 Cooling energy distribution in different cases

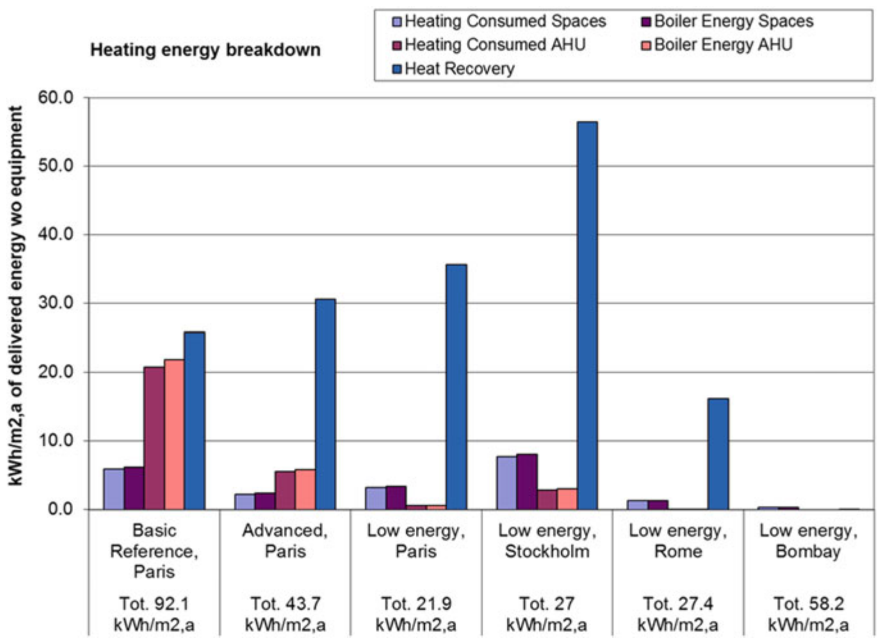

Fig. 5 Heating energy distribution in different cases

- The fan energy is important be reduced with VAV functionality in the ventilation system when targeting to more energy-efficient building as seen here between basic reference and advanced/low-energy cases. In this case study, the VAV function has been used in meeting rooms. If it would be used in all office rooms based on occupancy, this would generate even more significant reduction in the fan energy.
- Cooling energy use can be greatly reduced from the basic reference to the advanced/low-energy building and gets higher when building is located in Mediterranean conditions and especially tropical conditions. Water–air system for cooing is desirable because pumping energy is much smaller than fan energy.
- Even if the basis for comparison is middle European office building, all the specifications and selected systems work well in all simulated climate conditions. There can be only some minor changes for instance related to the airflow rates (CEN based or Ashrae based), but otherwise, specification should be applicable globally for modern office buildings.
- There are some things which can be done for yet better energy efficiency in the low-energy building case, for instance increasing the room temperature set point by 1 °C in cooling, it has small effect, but it does not change the overall picture and level of energy use. Also some other energy-efficient systems could be added, for instance a borehole cooling instead of traditional chillers and building-specific renewable energy sources such as wind generator of photovoltaic panels, but these were left out yet at this stage.

1.7 Concluding Remarks

The energy use of the office building with good standard construction, with construction including most common energy-efficient features, and with yet more modern technology for energy efficiency has been compared. The effects of different factors have been compared. Then, the most energy-efficient building has been analysed in different climate conditions: in Nordic and Mediterranean climates, and in tropical Asian climate. The energy use can be strongly reduced from basic reference building by using:

- energy-efficient structures especially for windows and solar shading.
- modern lighting system with intelligent controls.
- optimal HVAC system with very efficient heat recovery, good chiller design and air–water based chilled beam system with VAV functionality.

When building is located in Mediterranean or tropical climate conditions, big part of energy use comes from cooling/drying of supply air. All the specifications and selected systems fit in well to different climate conditions when designing modern energy-efficient office building.

2 Energy Targets in Architectural Competitions

Architectural competitions are one early-stage planning and design phase used typically for larger or more demanding or monumental buildings. The problem is that if energy performance targets will be applied after architectural competition (i.e. not included in the competition brief), this might be too late, and in worst case, the whole proposal has to be redesigned to meet the targets. This easily raises the question that the wrong entry has won the competition. To avoid such problems, energy performance targets are to be included in the competition brief among all other targets. The ultimate question is, how to do this in a proper way, so that:

- Energy targets will lead to integrated design and are considered from very first steps as massing and orientation issues;
- Unnecessarily complicated and detailed analyses can be avoided, because in very early stages, more robust and faster approaches are justified;
- All competition entries can be compared in fair way, i.e., everybody uses the same input data and reporting format, and energy performance is achieved with good design instead of input data manipulation.

In the following, energy targets and competition models are discussed based on experience from three recent international architectural competitions in Finland (Synergy, Low2No and Helsinki Central Library) and one smaller competition in Estonia.

2.1 Quantitative and Qualitative Targets

Energy targets are one issue in the sustainability, which can be measured with economic, environmental and social factors (EN 15643-1:2010). These categories could be measured with investment and life cycle cost, CO_2 emissions from energy and building material production and with indoor environmental quality (discussed in Chap. 5). It is important that quantitative performance indicators from all these three categories are included in competitions; however, they are not the most important ones. The main purpose of the architectural competitions is usually to find the best architectural and cityscape solution which has to come with excellent functionality and be as sustainable as possible. Therefore, in majority of competitions, sustainability and energy targets support the main targets. In technology-oriented or sustainable design development competitions, these targets can be also in the major role. In typical architectural competitions, the following categories of the assessment criteria are used:

1. Cityscape (compatibility with the site and fitting into the urban fabric);
2. Architecture (architectural design of the exterior and interior);
3. Usability (functionality/quality of working environment);
4. Ecological sustainability (indoor climate, energy performance and material efficiency);
5. Feasibility (construction and life cycle costs, possible to construct, operate and maintain).

When two last categories can be measured with quantitative (numeric) performance indicators, first three categories need qualitative assessment based very much on comparison of entries. Assessment of the competition entries is not a simple summing of scores of each category, because these categories had to sum up with sound overall solution and had to have good development potential—commonly required in competitions.

Quantitative nature of two last categories provides two options to specify assessment criteria:

- As minimum performance requirements, i.e., energy performance of X kWh/(m^2 a) primary energy has to be achieved, and for better performance, no credit is given;
- As a reference performance level which has to be achieved, but the entry with the best performance will receive the highest score, which is the typical assessment also for qualitative criteria (architecture, etc.).

In practice, there is no big difference which option is used, because if numeric performance indicators are required, they are taken into account by teams, and to do this, an integrated design approach is used that was the main purpose of such indicators. It is more important to define transparent and enough robust calculation procedure and input data for the calculation of performance indicators by teams. Some performance indicators could be better left to the jury, to be calculated during the assessment process of the entries. Typically, the construction cost has been calculated by the same consultant working for the jury, conducting the cost calculation of all entries.

2.2 Competition Models

Architectural competitions can be classified as one- or two-stage competition. One-stage competitions are with limited number of teams (qualified or invited) and energy analyses, and other calculations can be quite easily required. Two-stage competitions (especially international ones) may have many hundred up to about thousand entries in the first stage which means that energy calculations cannot be required during first stage and more simple criteria and verification has to be used. However, for the best proposals selected to the second stage, energy assessment is needed in order to be sure that the proposal could fit or could be developed to fit with energy performance and other numeric targets. In the second stage, similar calculations can be easily required as in one-stage competitions. To require the calculations, the calculation procedure, input data and reporting format have to be carefully specified in the brief.

2.3 Specification of Indoor Climate, Energy and Material Efficiency Targets

Indoor climate targets can be specified according to indoor climate classes of EN 15251 [5] discussed in Chap. 5 (or corresponding national code or standard). In the context of architectural competitions, it means a very short specification, including required room temperatures in winter and summer, ventilation rates and lighting levels. These values are needed also as input data, if energy simulations would be required.

Energy performance targets specification depends on assessment method used. There are two basic options:

1. To require energy simulations of a whole building and to specify energy performance target as primary energy;
2. To use simple indirect indicators and not to require energy simulations.

First option needs much more effort and also a very careful specification of the calculation procedure in the brief. In the case of two-stage competitions, energy simulations will be done in the second stage. This method was used in the case study reported in Sect. 3.

Second option does not enable the use of primary energy indicator, but more simple indirect energy performance indicators have to be used. Based on building envelope area data, the specific heat loss per room programme area can be very easily calculated as shown in Fig. 6. This simple indicator (with fixed building envelope element thermal properties) allows to control massing and façade design efficiency especially in heating-dominating climates, but is relevant for all European climates. To control cooling load and energy, very simple temperature simulations of some single typical rooms have to be required, and maximum cooling load target value has to be specified in W/m^2. This method (to fill in the table shown in Fig. 6 and temperature simulations of some representative rooms) can be seen as minimum for energy performance assessment. In two-stage competitions, the Table can be required in the first stage (and with final values in the second stage) whereas temperature simulations are relevant in the second stage. Main limitations of this method are cooling energy (cooling load provides some indications) and daylight which cannot be assessed. Heating energy cannot be directly seen as well, but as the specific heat loss coefficient correlates well with space heating energy need the entries can be compared adequately (the lower the specific heat loss, the lower the heating energy need).

In the case of both energy performance assessment methods, some graphical descriptions of HVAC and façade technical solutions are good to require in the brief for the assessment of entries. One schematic cross section of the building

Competition entry					
Room program floor area, m^2	1.0	Net floor area, m^2	1.0	Gross floor area, m^2	1.0
Heat losses through building envelope components				**Infiltration heat losses and thermal bridges**	
	U_i, W/(m^2·K)	A_i, m^2	H_{cond} W/K		
External wall	0.15	1.0	0.2	q_{50}, m^3/(h m^2)	1.5
Roof	0.09	1.0	0.1	No of storeys	1
External floor	0.12	1.0	0.1	q_{inf}, m^3/s	0.0000
Windows	0.80	1.0	0.8	H_{inf}, W/K	0.1
	A_{env}, m^2	4.0		Share of thermal bridges, %	20
	H_{cond}, W/K		1.2	H_{tb}, W/K	0.2
Specific heat loss of the building envelope, $H = H_{cond} + H_{tb} + H_{inf}$				H, W/K	1.4
Average U-value of the building envelope				H/A_{env} W/(K m^2)	**0.4**
Specific heat loss per room program floor area				$H/A_{Room\ program}$ W/(K m^2)	**1.4**

Fig. 6 Simple worksheet calculator for specific heat loss calculation with fixed (*grey shading*) values for all competition entries. *Yellow fields* are to be filled in—four building envelope area values are needed for calculation. Net floor area and gross floor area are additional information (for the efficiency assessment of entries) not used in the specific heat loss calculation

showing the operational concepts of the technical systems and façade solutions has been enough and has worked well in practice for this purpose. Such section should show ventilation, heating, cooling, daylight and solar shading solutions, as well as any other relevant active or passive solutions used. Mechanical room locations should also be shown and short explanatory text about technical concepts used has to be provided either in the same drawing or as an additional technical note of 1–2 pages.

If energy simulations will be required, it is important to fix main technical solutions in order to receive comparable results from all entries. This applies for building-site-dependent energy supply solutions (district heating, district cooling, gas, which renewable solutions can be used, etc.) which are to be defined. Similarly, the main parameters of ventilation (airflow rates, operation hours, heat recovery efficiency, specific fan power) are better to fix for energy calculation; however, other technical solutions for ventilation (mixed mode, another air distribution, etc.) could be accepted. If teams use other than the reference solution, they can assess energy savings with actual solution relative to the reference solution, that will make the assessment of results easier (instead of quite arbitrary results difficult to judge because of different solutions and system efficiency parameters used by teams, it can be seen how much savings have been accounted for each specific solution). For the cooling, it is at least relevant to define in which rooms a room conditioning has to be used (in addition to central cooling of supply air in AHUs).

All input data needed in energy calculations have also to be defined—occupancy schedules, internal heat gains (lighting, appliances, occupants), ventilation airflow rates, temperature set points in winter and summer, etc. Depending on the purpose, the *U*-values of the building envelope components could be fixed or not. Such limitations indeed reduce the freedom of design and should be well justified. Experience from competitions has shown that if the main technical solutions were not fixed, the entries ended up with solutions with highly inconsistent efficiency, ambition and cost, and the results were very difficult to compare without recalculation. If in addition to main technical solutions, the calculation procedure, input data and reporting format were well specified; for majority of the entries, the energy simulation results were assessed as reliable, and some recalculations were needed only in specific cases. Energy calculation procedure and input data have typically to follow national building code (relevant parts can be translated) and used as appendixes of the brief. If the building code does not support energy simulation, the energy calculation methodology has to be described in the brief that needs a significant effort; however, the general calculation principles are well known.

Material efficiency targets can be specified in similar fashion to primary energy. The specific CO_2 emission indicator shows how many kilograms of CO_2-emissions per floor area are released during the production of construction materials of main structures. Similarly to energy calculation procedure, the calculation of building material volumes has to be well specified. Such calculation is typically limited to the load-bearing structures and building envelope (finishing materials, partitions and other less important components will not be calculated). The calculation method is specified in EN 15978 [6] and a case study example is reported in Sect. 3.

3 Architectural Competition Case Study: Synergy in Helsinki

Viikki Synergy competition was one-stage competition held in 2010–2011, where six qualified teams prepared comprehensive design of about 20,000-m^2 office and laboratory building as shown in Fig. 7 [8]. The competition entries required were relatively detailed for such competition, including energy simulations and embodied carbon analyses. In this chapter, the assessment criteria for sustainability from quantitative measuring point of view are discussed.

The innovation of the competition was the assessment criteria for sustainability, summing up the energy performance and material efficiency data in $kgCO_2/m^2$ units in the assessment process. This criteria and lessons learnt from the competition can be utilized in future competitions in order to design and build sustainable buildings.

3.1 Assessment Criteria of the Brief

The competition brief used well-specified assessment criteria, from which roughly 50 % was quantitative (measurable with performance indicators as tons of CO_2 or Euros) and another 50 % qualitative ones related to architectural components. In Viikki Synergy, four main categories with roughly equal importance were as follows:

Ecological sustainability including energy performance and material efficiency

- Urban and architectural quality.
- Usability (functionality/quality of working environment).
- Feasibility (economic efficiency and quality of technical solutions).

Fig. 7 First-Prize-awarded-entry Apila of the competition (a low-rise large building in *front right*)

These categories had to sum up with sound overall solution and had to have good development potential. Referring to good architecture, reasonable cost and sustainable use of energy and material resources, the categories were supported by transparent assessment framework well described in the brief.

Ecological sustainability was measured with energy performance and material efficiency. Energy performance followed the target of EPBD recast for 2019–2021, nearly zero-energy buildings, which was the basis for energy performance target value of 80-kWh/(m^2 a) primary energy without tenants electricity (all other energy flows included according to EN 15603). It was assessed that 80 kWh/(m^2 a) per programme area will correspond roughly to 70 kWh/(m^2 a) per net area (the difference is caused by corridors not included in the room programme). Energy carrier factors to calculate the target of 80 kWh/(m^2 a) were 2.0 for electricity, 0.7 for district heat and 0.5 for renewable fuels. For the energy supply systems, it was specified to use on-site solar electricity production corresponding to 15 % of total electricity use (facility + tenant electricity). This fixed amount was justified with high cost of PV-panels, and making it easier to compare the proposals. All other solutions for energy performance were let open.

Comprehensive energy performance calculation guidance was provided as the appendix of the competition brief. This was necessary, because the primary energy calculation frame provided in the Finnish building code D3 2012 was not available. In future competition briefs, this part can be simply replaced by the reference to relevant calculation frame, such is the building code in the Finnish case.

Material efficiency was measured in $kgCO_2/m^2$ floor area and teams competed to achieve as low value as possible without compromising with other criteria. The assessment was limited to the main structure's carbon footprint that was derived from the carbon dioxide emissions resulting from the building materials' manufacture and the materials' possible carbon dioxide storage. For the material emission calculation, the specific emission values were provided in the brief as shown in Table 3.

In the assessment, the energy performance and material efficiency data were summed in $kgCO_2/m^2$ units by the use of specific emission factors for energy carriers instead of primary energy factors. Such assessment resulted in life cycle CO_2 emissions, as well as LCC in the economic efficiency assessment. For the LCC, the jury ordered construction cost calculations from the consultant not being involved in the completion (i.e. cost calculations were not included in the brief). The same consultant provided cost calculations for the all six proposals.

Energy performance was also recalculated by another consultant for two proposals. As the results were very close to those provided by the competition teams, the energy calculation of the rest of proposals were not recalculated to save time and money.

Relatively easy and fast cost and energy calculations as a part of the assessment procedure were possible, thanks for the building information models required in the brief. These BIM models made it possible to analyse the proposals with the software tools used for cost and energy calculations.

As a result of assessment, the proposals were compared in the life cycle carbon (tons of CO_2) and life cycle cost (M€) scale, Fig. 8.

Table 3 Specific emission factors for the material emission calculation. Due to somewhat local origin, the values have mainly Finnish references and apply in Finnish conditions. Such data can be found from environmental product declarations according to EN 15804 [7]

Material	Mass per volume kg/m^3	Greenhouse gas emission gCO_2-eq/kg[a]	Carbon storage g CO_2-eq/kg	Source[c] Appendix 19.2
Concrete products				
Steel used for concrete reinforcement	7,850	440		llSl European average, EAF-route
K35 ready-mixed concrete	2,400	140		RT environmental declaration
K90 ready-mixed concrete	2,400	200		RT environmental declaration
K60 multicore slab	2,400	170		RT environmental declaration
K60 double T-slab	2,400	210		RT environmental declaration
Metal products				
Steel pipe	7,950	1,090		RT environmental declaration
Structural hollow sections, steel pipe pics, steel sections	7,850	1,090		RT environmental declaration
Welded steel beam	7,850	780		Rautaruukki
Hot-dip galvanized steel products	7,850	1,040		Rautaruukki
Cold-rolled steel sheets and coils	7,850	880		Rautaruukki oyj llSI-data Ruukki
Hot-worked steel sheet	7,850	730		Ruukki, RT environmental declaration
Paint-coated steel sheets and coils	7,850	1,070		RT environmental declaration
Steel wire rope	7,300	2,680		Fundia wire oy
Aluminium profile (85 %)	2,700	3,640		Scanaluminium
Brickwork products				
Lime brick for external cladding	1 750	180		Optiroc Oy
Lime brick for dividing walls	1,750	150		Optiroc Oy
Burnt clay brick	1,300	220		Wienerberger Ov
Block of lightweight aggregate concrete	700	330		Betonikeskus ry

(continued)

Table 3 (continued)

Material	Mass per volume kg/m^3	Greenhouse gas emission gCO$_2$-eq/kg[a]	Carbon storage g CO$_2$-eq/kg	Source[c] Appendix 19.2
Expanded clay aggregate concrete pand	880	270		Rakennusbetoni- ja elementti Oy
Autoclaved aerated concrete	440	280		RT environmental declaration
Building mortar M100/600	1,800	140		Optiroc-house
Block mortar M100/500	1,800	220		Optiroc-house
Thin mortar joint	1,800	220		Optiroc-house
Lime plaster 50/50	1,800	130		Optiroc-house
Average filter	1,800	170		VTT research report
Concrete roof tile	44	140		Ormax, lafarge roofing oy
Wood and board products				
Glued laminated timber	440	330	1,600	RT environmental declaration
Sawn umber	480	70	1,600	RT environmental declaration, VTT optiroc-house
Dried floor board/plank	480	90	1,600	LCA-saha data-sheet
Planed board/plank (for indoor use)	480	110	1,600	LCA-saha data-sheet
Glued laminated bean	500	230	1,600	Pöyry
Fibreboard, softboard	300	420	1,600	RT environmental declaration
Medium density fibreboard	780	270	1,600	Karlit ab/Trätek envi. decl.
Hardboard	950	130	1,600	Karlet ab/Tratek envi decl.
Chipboard	670	390	1,600	VTT research report/Puhos-board Oy
Standard conifer plywood	450	680	1,600	RT environment declaration
Standard birch plywood	660	720	1,600	Puuinfo Oy, RT environmental declaration
Gypsum board	9 or 11.7	390		RT environmental declaration
Plastic products				
Polyethene (HD)	940	2,410		Association of Plastics Manufacturers in Europe
Polypropylene	905	2,100		ELCD database, polypropylene fibres (PP)

(continued)

Table 3 (continued)

Material	Mass per volume kg/m^3	Greenhouse gas emission gCO$_2$-eq/kg[a]	Carbon storage g CO$_2$-eq/kg	Source[c] Appendix 19.2
LDPE (Low-density polyethylene) foil	940	2,100		Apme.org
Insulating materials				
Wood fibre insulant from collected paper—Termex	26–65	220	800	RT environmental declaration
Wood fibre insulant from collected paper—Ekovilla	30–65	180	800	RT environmental declaration
Expanded clay aggregate/lightweight aggregate	290	420		Optiroc Oy
Stone wool	22–250	990		RT environmental declaration
Glass wool	20	800		Isover Oy
PUR. polyurethane		4,230		VTT calculations on SPU-insulant
Polystyrene, floor board	15	3,600		Apme org
Extrusion-compressed polystyrene	38	3,600		Apme org
Other materials				
Bitumen–polymer sheeting	–	1,120		VTT optiroc-house
Sheet glass flat glass	2,500	BCD		VTT energy-corrected Pilkington Ltd
Window frame	Calculate yourself in the Excel sheet using the material amounts			
Reused (i.e. old ones) structures and materials[b]		0		

[a] At factor gate, the jury may complement the calculation by the emissions of the transport (especially its long distance)
[b] The jury may complement the calculation lay emissions from the processing and transport of the material
[c] A large part of the sources and values collected by Timo Rintala/Pöyry RT Environmental declarations: www.rts.fi
Rough estimates of the carbon storage were based on the RT Environmental Declarations of following products: sawn timber, glued laminated timber, birch plywood. The carbon storage of wood fibre insulants, made from waste paper, is a very rough estimate based on materials of the insulant.

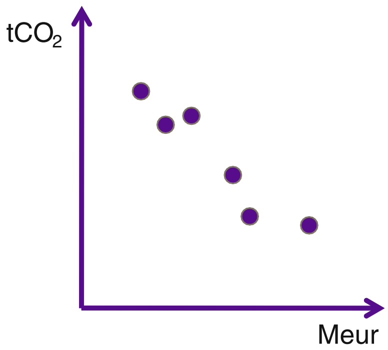

Fig. 8 Ecological and economical performance map used in the assessment of proposals in Viikki Synergy competition. *All dots* (six proposals) are fictive examples, representing the jury expectations about less ecological proposals with lower cost (*dots in the left*) and more ecological proposals with higher cost (*dots in the right*). See the real results reported in next section

3.2 Results

The key figures for the competition entries' energy and materials efficiencies are shown in Table 4. Primary energy values describing total energy use calculated with energy carrier factors (2.0 for electricity and 0.7 for district heating) are first presented in MWh/a units for a reference building solution complying with valid minimum code requirements, and for the design solution with conventional energy supply solutions as specified in the competition programme. Primary energy for the actual design solution is then presented in MWh/a and kWh/(m^2, a) units, of which the latter reflects the programme floor area, and does not include user electricity according to the competition programme's definition. The energy use of the actual design solution has been calculated as the CO_2-e emissions caused by 30 years of energy use, with an approximate specific emissions factor of 150 kg CO_2-e/MWh for next 30 years. This specific emissions value was used both for electricity and district heating.

The main structure's carbon footprint was derived from the carbon dioxide emissions resulting from the building materials' manufacture and the materials' possible carbon dioxide storage. Solaris has functioned as a carbon sink because its carbon dioxide storage has been larger than the emission caused by the manufacture of its building materials. The breakdown of the carbon footprint is shown in Table 5.

The table's bottom line shows the sum of 30-year energy use and the main construction's carbon dioxide emissions. This key figure serves as the estimate for the property's 30-year carbon footprint.

The results show that the leaders are Apila in energy performance and Solaris in material efficiency. The results for energy performance are fairly even, with Pastorale, however, somewhat separated from the rest. In terms of material efficiency, 191910 and Pastorale are clearly weaker than the other entries.

Table 4 Key figures for competition entries' scope and costs, as well as energy and materials efficiencies; the three best results are shown in boldface

Competition entry	1 Solaris	2 Valaistus	3 Pikkukampus	4 Pastorale	5 Apila	6 191910
Rentable area, m^2 (programme area 12,855 m^2)	14,000	13,100	14,600	15,800	12,700	14,800
Net floor area, m^2	18,300	18,800	18,200	21,500	19,800	20,400
Gross floor area, m^2	20,600	20,300	20,100	23,600	21,800	23,800
Construction cost estimate, M€	**54.9**	**54.6**	58.5	57.7	**54.1**	61.1
Primary energy, reference building solution complying to minimum code requirements, MWh/a	5,104	**4,513**	4,575	**4,272**	4,523	**4,053**
Primary energy, design solution with conventional energy supply solutions, MWh/a	3,576	3,517	**3,502**	3,631	**3,508**	**3,281**
Primary energy, actual design solution, MWh/a	2,851	**2,765**	2,830	2,985	**2,674**	**2,780**
Primary energy, actual design solution, kWh/(m^2 a) without user electricity	99	**92**	97	109	**85**	**93**
30-year carbon dioxide emissions of energy use, tCO_2-e/a	7589	7146	**6,904**	7,726	**6,005**	**6,102**
Carbon footprint of main structure, tCO_2-e	**−470**	**147**	1,600	3,269	**481**	4,013
Carbon footprint of main structure, $kgCO_2$-e/m^2	**−37**	**11**	124	254	**37**	312
Total carbon footprint of 30-year energy use and main structure, tCO_2-e	**7,119**	**7,293**	8,504	10,995	**6,486**	10,115

The key figures for energy use have been checked so that energy use categories reported are identical in all entries. Additionally, to check the results, energy simulations were carried out for two entries, whose results were very close to the figures provided

Table 5 Material emissions and carbon storage of competition entries

Competition entry ($kgCO_2$-e/m^2)	1 Solaris	2 Valaistus	3 Pikkukampus	4 Pastorale	5 Apila	6 191910
Material emissions of main structure	179	151	n.a.	256	260	646
Carbon storage of main structure	−215	−140	n.a.	−2	−222	−335
Carbon footprint of main structure	−37	11	124	254	37	312

Carbon footprint used in the assessment was calculated as a sum of material emissions and carbon storage. Note that the calculation method of EN 15978 [6] not taking carbon storage into account in the life cycle was not available at the competition time.

When assessing the 30-year total emissions, Apila's 6,500-t emissions are the lowest. Next are Solaris and Valaistus at 7,100 and 7,300 t, respectively. Pikkukampus is situated midway on the scale at 8,500 t, and the two remaining competition entries 191910 and Pastorale are clearly weaker than the others, exceeding the 10,000-t limit.

In the main structure's carbon footprint calculation, both material emissions and carbon storage were taken into account. Full inclusion of the carbon storage is a simplification that affects remarkable results and means the assumption that materials will stay forever in the building structures. Another and more accurate possibility will be to include the carbon storage only for materials reused or recycled after demolishing of the building. The effect of carbon storage is shown in Table 5. Pastorale had mainly concrete structures, and the carbon footprint is much higher compared to mainly wooden entries Solaris, Valaistus and Apila. In material emissions, the difference is less significant, showing the meaning of the carbon storage treatment in the calculations.

The results of the competition works' ecological sustainability were compared to life cycle costs as certain competition entries have required more substantial actions to achieve good energy performance, which for their part affects construction costs. An extreme example of this was 191910, in which the building's uneconomical shape (a remarkably larger external surface area than the other entries) has been compensated with a clearly enhanced level of thermal insulation, as well as with a low-pressure ventilation system integrated with a structure. Thirty-year life cycle costs (calculated as the sum of estimated construction costs and estimated 30-year energy expenses) are compared to 30-year total emissions in Fig. 9.

From the standpoint of ecological sustainability, a cost comparison of the three best competition works (Apila, Solaris and Valaistus) demonstrated, within the framework of calculation accuracy, virtually identical construction costs, the cost difference for these three entries falling within a range of 1.5 %. The values of the estimated construction costs for Pastorale, Pikkukampus and 191910 were significantly larger (+7–13 % compared to the most economic one). Thus, the best in terms of energy performance, Apila, was also the best in terms of life cycle costs, with Valaistus and Solaris following close behind.

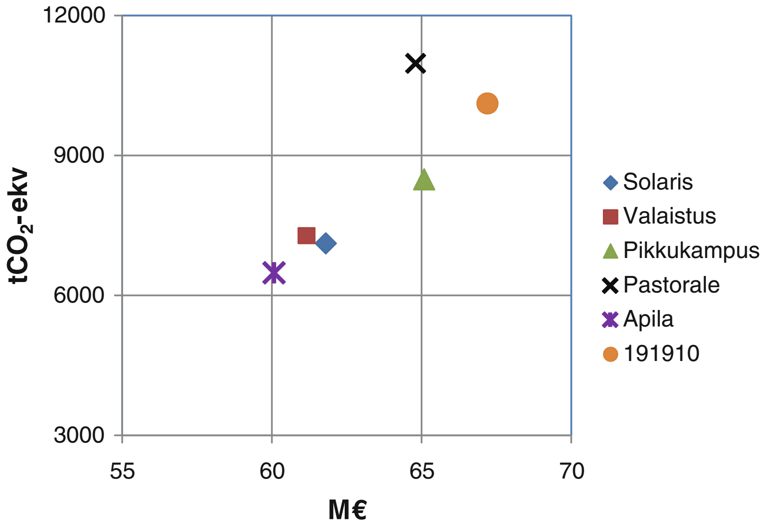

Fig. 9 Placement of competition entries on scale of 30-year life cycle costs and carbon footprint of main constructions and 30-year energy use. The competition entries form two fairly distinct groups; the group formed by Apila, Solaris, and Valaistus simultaneously has clearly lower emissions and costs

3.3 Conclusions

Competition entries have shown that there are not necessarily conflicts between sustainability and architectural categories; as in many cases, these different categories can support each other and lead to proposals with different and rich architecture.

Inclusion of quantitative energy performance, material efficiency and economic efficiency targets will direct the design and selected concepts from very first steps of design teams. Design teams have shortly noticed that integrated design is needed to meet the performance criteria. However, bearing these criteria in mind, there is still a lot of room for functionality and architectural components. The criteria used did not limit the architectural quality that was demonstrated by various massing alternatives proposed.

It may also be seen so that if all teams meet exactly the specified quantitative performance targets (kWh/m^2, kgCO$_2$/m^2 at roughly the same cost), the winner will be selected very much based on functionality and architectural components, which is not different from traditional architectural competitions. In such a case, quantitative performance targets just have assured the technical quality of the proposals, i.e., being energy, material and cost efficient. In reality, there are usually differences between the proposals, i.e., how well they meet energy and material targets and quite often in the economic efficiency, and these differences may serve as decision bases between proposals with roughly equal architectural quality.

Best proposals of Viikki Synergy competition were able to sum up high architectural quality, good functionality, energy and material efficiency as well as cost efficiency. It can be concluded that for the jury, there was no need to select between ecologically efficient and cost-efficient entries, but selection was made within the group of entries being both ecologically and cost efficient.

For the future sustainable design competitions, there are some issues in the competition programme to be further developed. Primary energy calculation can be done in Finland according to new building regulation, Finnish building code, Part D3 2012, which was not available at the competition time. D3 2012 specifies similar calculation framework as was in the annex of the competition programme; therefore, this annex can be simplified. Carbon footprint calculation was not fully standardized at the competition time and will still need detailed guidelines in order to achieve meaningful comparable results. Inclusion of the carbon storage in the building life cycle assessment was not correct according to EN 15978 [6] calculation method, which specifies carbon storage assessment in the supplementary information module beyond the building life cycle, dealing with materials reuse and recycling. Therefore, it can be recommended to limit carbon assessment in architectural competitions to building life cycle, meaning that carbon storage assessment would not be done. Another detail in carbon calculations were the foundations causing some confusion. In order to keep reasonable accuracy, it can be suggested to provide model solutions for foundations in the competition programme so that reasonable alternatives for lightweight and heavyweight structures and construction frame types are available with load-bearing capacity and carbon footprint data. This will avoid the unnecessary effort of foundation sizing as well as possible under or over sizing of foundations what was suspected in this competition in a couple of cases.

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