DECISION-MAKING AID TOOL FOR THE EVALUATION AND IMPROVEMENT OF THE ENERGY PERFORMANCE OF STOCK OF BUILDINGS

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Abstract

The scope of this research deals with the reduction of energy consumption in existing buildings through the development of a tool. This tool is intended for building professionals, particularly managers, to help them manage their building stock and improve energy performance.

Several studies based on simulation and benchmarking methods have been carried out to improve energy effectiveness in buildings. The majority of these studies and their corresponding tools treat each building separately. However, a large number of existing buildings need renovation. For this reason, building stock managers need new approaches, new skills and new tools to allow them to treat the building stock as a whole. The decision-making tool for the evaluation and improvement of building energy performance could be one of these tools.

As an initial approach, several key functions were defined for this tool:

- State analysis of a buildings stock
- Decision-making aid:
  - To decide improvements to bring,
  - To define priority actions and coupling strategy of this actions according to the managers constraints,
  - To evaluate impacts of the improvements on the consumptions and factures.

For the development of this tool, the two following methods are used:

- Benchmarking: this method allows the comparison between real consumption or consumption obtained by simulation and reference consumption,
- Computer simulation: with this method, parametric studies are made. These studies will allow the hierarchical organization of the improvements and the evaluation of their impacts on consumption.

Introduction

The European Energy Performances of Buildings Directive (EPBD) [10] asks that a diagnosis of energy performance be made before the sale of any building in 2006 and before any rental in 2007. The objective of this directive is to identify buildings with low energy performance and persuade their owners to invest in their improvement. Hence, a new « energy Label » will be set up to indicate the building energy performance (Type A to G according to the consumption in kilowatts-hours by square meter or CO_2 per square meter). This label will also compare stock with each other and identify the highest energy consumers. As a result, local communities could reduce the land tax for owners who made works contributing to the improvement of their building's energy label.

Managers of buildings' stock need to get ready to apply the new Directive. Several projects and programmes are already realized and the others are progressing to answer some requirements of this directive (Europrosper, Display, EPLABEL [5], ENPER-EXIST, EPA-NR…). Most of these projects and programmes are based on labels:

- To facilitate the transfer of clear and reliable information on the energy performance of buildings,
- To make energy efficiency more attractive.

But today, managers of buildings stock didn't have the adapted tools to deal with a large number of buildings. They needs methods for an hierarchical and efficient approach that help them to prioritize the buildings to treat and the more efficient actions to apply to a large number of buildings. Managers of buildings stock need to answer several questions to make a commitment in the direction of energy saving.

Some of these questions are written in the following lines:

- How to compare the energy efficiency of buildings of the stock in comparison with energy "standard"?
- How to compare the energy consumptions of a building according to the average consumptions of the stock?
- Which buildings of the stock need improvements in priority?
- How much are the energy savings regarding to the improvement and how to classify the various solutions, at the level of stock?
- What type of system management for a stock of buildings could be developed?

This paper presents the elaboration of a decision-making aid tool intended for helping managers of buildings' stock to obtain the responses to their questions and to evaluate and improve the energy performance of their buildings.

Objectives

To improve the energy performances of existing stock of buildings, the following actions could be taken:

- Improvement of buildings' envelope,
- Use more efficient equipments (HVAC systems, lighting, …) or improve the existing one,
- Use new efficient management and control systems or improve the existing one.

To analyze the performances of their stock of buildings and to apply efficient actions, the managers need not only powerful tools but also tools that are adapted to their managerial and technical constrains. The main approaches that could be used to develop those tools are based on:

- Statistical analysis,
- Computer simulation,
- Benchmarking.

This research work deals with the reduction of energy consumption by giving, to the building professionals, particularly managers, methods to facilitate management of their buildings stock. These tools help them to choose the best decisions for the rehabilitation of their buildings stock by taking into account their constraints. In this study, the development of a decision-making tool taking into account their needs and their constraints is proposed. This tool may couple the simulation and the benchmarking methods. Its outputs might be solutions for the evaluation and the improvement of buildings stock energy performances.

The goal of this paper is to make the state of the art of the existing methods for the evaluation of the energetic performance of buildings. These methods will be compared one to the others according to the specifications described for the development of the decision-making aid tool. This comparison may highlight the advantages of each method and be the bases of the development of a new approach.

Tool requirements

The aid decision-making tool [9] should give to the stock manager some information [8] to evaluate the energetic performance and suggests some improvement to increase their efficiency. These informations could be:

- The primary energy consumptions,
- The corresponding CO_2 emissions,
- The energy performance classification (from A to G): it is an indicator of energy performance and CO_2 emission (by analogy with the classification of the products electric household appliances). It allows users of this tool to easily show the energy performance,
- The improvement suggestions, their costs, the time of depreciation, the envisaged energy savings and their impact on the energy performance classification.

Approach

Figure 1 shows the approach followed for this work.

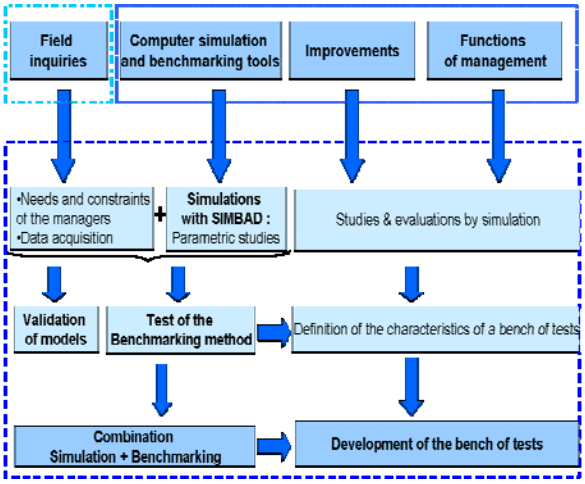

Figure 1: approach for work

The analysis of the existing studies on the energetically performances of the buildings stock improvements (methods and tools to evaluate and increase energetically performances, different buildings stock improvements and different management functions), the field inquiry with future end users of the tool and the development of the tool (with a close loop process to correct and adapt the end-users requirements) will be done in the same time.

Before having a first version of the tool, inquiries have to be made to correct and adapt the book of specifications. After the development of the first version of the tool; also in this case, inquiries have to be made to highlight gaps of this version.

An adapted method has to be chosen to develop the tool. This method must allow developing software accessible and easy to use; which could make a buildings stock classification and could suggest improvements of:

- The whole stock,
- One or several groups of stock buildings,
- One or more stock buildings.

This method has to be validated after it development.

Real data collected from a set of buildings (consumptions and characteristics of buildings' stock) will be used to develop and validate a simulation tool that can be used to play different scenario (buildings' stock with different level of performances, different management approaches…)

Field inquiries

Field inquiries are carried out with some managers of buildings stock and public managers ([1]). The goal of this inquiry is to determine the specific needs and the constraints of buildings professional. It also allows to collect data in order to well design the aid decision-making tool called "Tool for the evaluation and increasing of buildings stock energy performances". Data collected are the basic informations for the definition of the adapted method used for the development of the tool.

[1] Inquiries already made with a manager of the equipment ministry, managers of the schools in Paris and Strasbourg commune. Inquiries expected on September with university of Bordeaux manager.

The selected method for the tool will be a function of:

- The available data. It will define the inputs of the tool (invoices, consumption, intrinsic envelope characteristics, and equipments characteristics...)
- The end-user needs (manager…). They will define a part of the outputs of the tool.

Some inquiries included visits of school buildings to collect a maximum of data.

Actually, the inquiry task is running and will be finalize at the end of the year 2005. At this moment, two inquiries have been carried out. The first was with the ministry of the equipment of France, and the second with the municipality of Strasbourg.

Inquiries conclusion

At the level of buildings' stock managers, it is:

- Possible to have access to energy consumption of a site (group of buildings connected to the same electrical meter),
- Difficult and sometimes impossible to have access to the whole characteristics of each individual building. It is easier to have access to information at the level of a whole stock of buildings.

So, it is important to give priority of the approach that uses energy consumptions to evaluate the stock of buildings performances and detailed diagnostic approach for the buildings' stock with high energy consumption.

For these reasons, different existing methods allowing evaluation and improvement of building performance are studied. The comparison between these methods leads to choose the most adapted one to develop each functionality of the decision-making aid tool for the evaluation and improvement of the energy performance of stock of buildings.

Existing methods

The Table 1 [1] & [4] shows a brief comparison between the different existing methods of energetic efficiency evaluation. Strength and weakness of each method is highlighted.

Models	Examples	Strength	Weakness
Statistical [14] Regression Models	Linear, Multiple-linear, Change-point, degree-day, etc.	Easy to establish	Fair accuracy
Computer Simulation	DOE-2, EnrgyPlus [3], BEST, etc.	High accuracy, detailed description	Time consuming, Large building information
Benchmarking [7]	Europrosper, Display, etc.	Explicit results	Classification basing itself only on consumption
Other models [6]	Neural Network [11], Fourier Series, Support Vector Machines [2], etc.	High accuracy	Large pool of hourly data

Table 1 : Comparison of different existing methods

Conclusion

According to the tool book of specifications, the study and analyse of the existing methods and their functionalities allows to know the most adapted methods for the tool development.

This comparison between existing methods allows to conclude that:

- To evaluate buildings' stock consumptions: In this measure, the tool user would like to know the class of its buildings' stock. The computer simulation is not necessary in this step. Fewer inputs could be used if the benchmarking method is chosen in this case.
- To improve buildings' stock performances: Simulation is the adapted method for this case. With simulation, parametric studies can be made (buildings' stock performances after different improvements…) to evaluate the impacts of improvements.

Development of the decision tool

This section details steps followed for the development of a method and its validation.

Computer simulation with SIMBAD

This work will start with simulations. The results of the simulations will allow us to test the reliability of the other methods. The known consumptions origin obtained by simulation (simulation inputs: envelope and systems characteristics) will allow to master the outputs obtained by the other methods using the consumptions as inputs.

SIMBAD Building and HVAC Toolbox, developed by CSTB till ten years [13], is selected as simulation tool. The flexibility of this tool concerning the implementation (easily multiplication of the buildings) justifies this choice. Thus, the simulation of buildings stock is possible starting from the definition of some standard buildings.

SIMBAD (SIMulator of Building And Devices) is the first HVAC toolbox developed under the MATLAB/SIMULINK environment. This toolbox provides a large number of ready to use HVAC models and related utilities. This toolbox, in connection with other existing toolboxes (Neural network, fuzzy logic, optimisation), will offer a very powerful and efficient tool for the applications listed above. The toolbox is made up of 12 groups of models and utilities and 1 group of pre-defined examples of installations with various HVAC heating or cooling systems. The next figure shows a part of the groups available in the SIMBAD Toolbox:

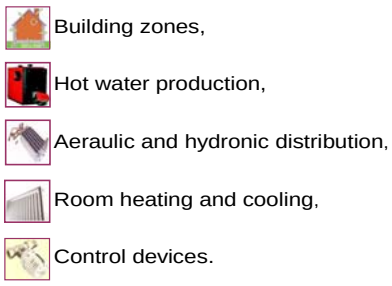

Figure 2: Some groups available in the SIMBAD Toolbox

Benchmarking

The "Benchmarking" method uses the energy consumptions as input data. This method is easier to use because the input data needed is reduced. However, in some cases, especially when using only electric energy sources, it is difficult to distinguish between the different energy consumptions (heating, lighting, ventilation equipment…) in an energy invoice. This does not facilitate the investigation of the end uses which are more energy consuming.

To develop the tool, benchmarking method is implemented. This method could make an energy

classification of the stock buildings and distribute whole consumptions on end uses.

Figure 3 shows the process used to validate the Benchmarking method. Simulations will be carried out with the SIMBAD Toolbox according to the stock data to evaluate energy consumptions. These consumptions are then used as inputs for the Benchmarking method. The known sources of consumptions allow us to analyse Benchmarking method outputs.

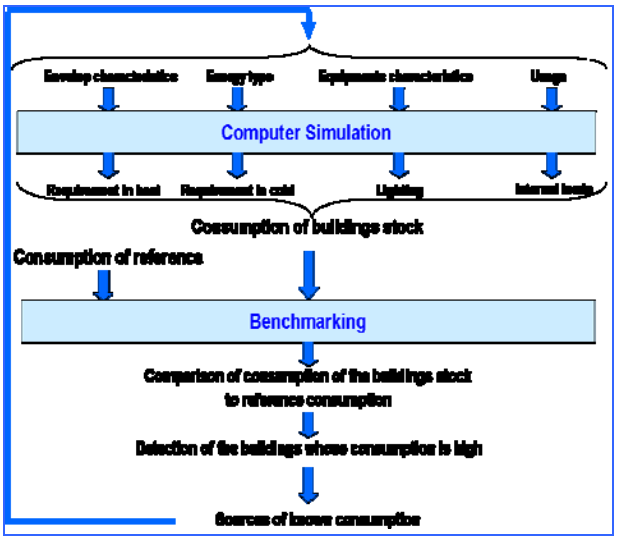

Figure 3: Test of benchmarking methods

Combination of the computer simulation and the benchmarking

The more adapted method should combine benchmarking and simulation methods.

The benchmarking method compares the buildings stock consumption to the reference consumption, makes a classification of buildings' stock and suggests improvements to increase their performances.

The computer simulation draws up a list of improvements with coupling strategies by taking into account the constraints of the managers. Then, the impact of these improvements will be expressed in calculation of investments, of return of investments and made savings.

First vision of the aid decision-making tool

Figure 4 shows the first vision of the tool. From the stock characteristics, the real consumptions and the use of the building, with data bases and constraints of stock managers, the tool gives a selection of improvements and coupling strategy, their investments costs, their return investment costs and the envisaged energy savings.

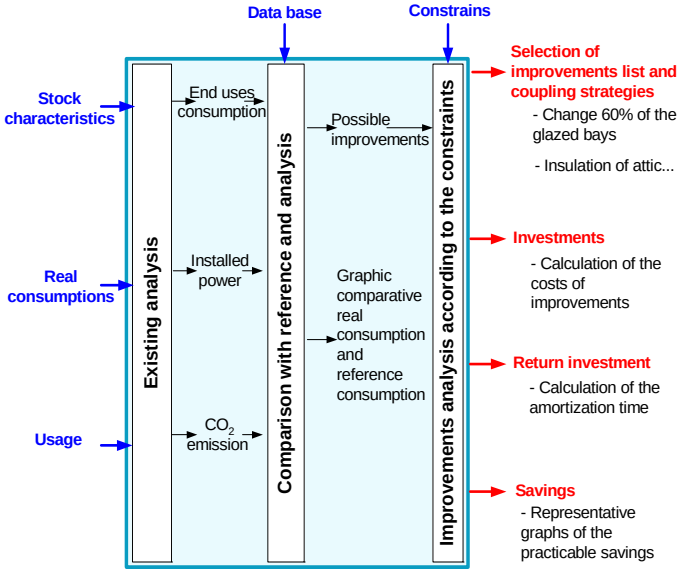

Figure 4: first vision of the tool

Figure 5 shows a first vision of these functions:

- Analyze of the existing buildings' stock:

The tool initially will allow the managers to better know their stock. A general vision on the stock through its consumption is given. Then, a more detailed vision of buildings' stock with highest energy consumptions are identified through an energy classification. This classification of the buildings' stock will be carried out according to their consumptions based on ratio such as kWh per square meter or per occupant. These buildings could be classified by comparison to the others or to a fixed reference. The standard classification could be made for the same type of buildings' stock or for buildings' stock from different types. The typology of the buildings' stock is based on criteria such as the use, the type of construction, the HVAC equipment, the climate...

For buildings' stock with same type standard but with different ladder or different use (stock of schools with or without canteen, stock of colleges with or without dormitories...), or for buildings' stock of different types (complex buildings' stock: different use (hotels, schools, trade...), different climate...), a correcting factor of energy consumption may allow to put them at the same scale. At the same scale, buildings' stock can be compared ones with

the others. This classification could identify the buildings' stock and their energy performance.

- Decision-making aid :

With simplified models, simulations will allow the evaluation of the buildings' stock improvements:

- Reduction envelope losses,
- Improvement in the equipments efficiency,
- Improvement in the regulation (optimization of the revival, new scenarios of control...),
- Improvement of production output (use of renewable energy...)...
- To define priority of actions (single, coupled…)

The simulator becomes a decision tool. At this stage, managers will have a list of improvements with their impacts according to its constraints (technical, financial, organisational...) on the energy consumptions and the profits estimation.

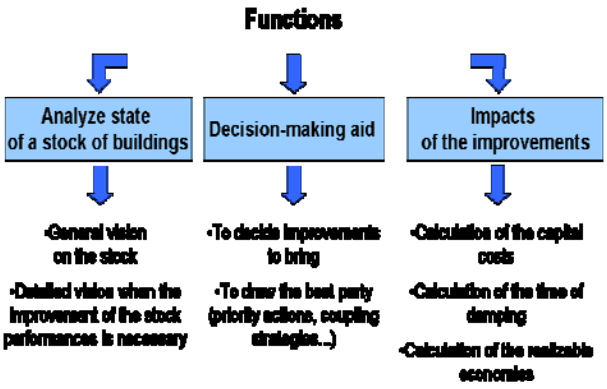

Figure 5: First vision of tool functions

Decision tool functionalities

Data bases will be implemented in the tool and contained:

- The reference consumptions of all the type of buildings: these values are used to locate its own real consumptions and to attribute it an energy class (From "A" best practice, to "G" worst practice).
- A calculation method which makes the percentages of consumption distribution on the consuming end uses (heating, ventilation, air-conditioning, lighting...): some characteristics of the buildings' stock (specific buildings...) and of the occupation (a number of hours per day of occupation...) have to be implemented in this method. It allows to divide up energy consumptions on the consuming end uses and thus to determine the origin of the over consumptions.
- Measurements related to improvements [12]: A predefined list of improvements is available for the stock level (improvements generalized on the whole stock or on a priority buildings) or for the building level (improvements for each building of the stock).
- Constraints: a list of the most frequent constraints will be available. Users will choose from this list their proper constraints. If users have other constraints, they will be able to add them. These new constraints will be taken into account by the tool and will also be added in the data base.

According to the needs of users, the tool will have various inputs as the Table 2 shown.

User of the tool needs	Inputs data
• Comparison of real consumption with reference consumption • Class of Buildings' stock performances	• Real consumption • Buildings' stock type • Buildings' stock areas
• Consumption distribution per end uses • List of potential improvements	• Most buildings' stock characteristics
• Improvements impacts	• Most buildings characteristics

Table 2 : Inputs for the tool

Figure 6 shows the case where the manager wants to check the energy efficiency of his building compared with reference values.

In this case, users have to specify a reduced number of inputs. The comparison between real consumption and reference consumption is carried out by the benchmarking method.

Then, the manager will know the classes of his buildings stock. This classification allows to highlight buildings with highest energy consumption.

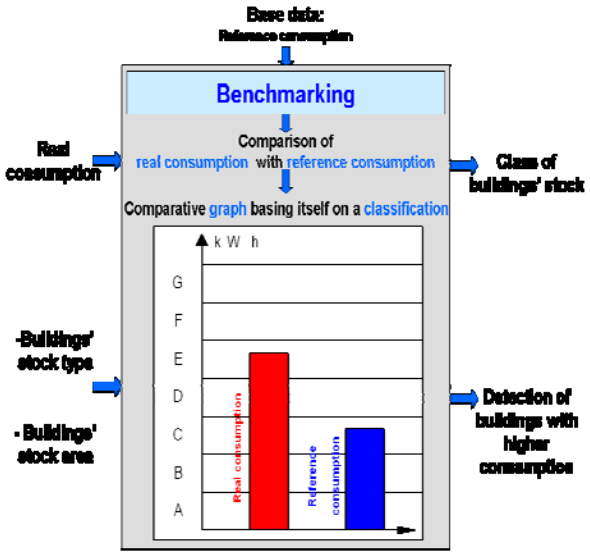

Figure 6: Step 1 (general benchmarking).

Figure 7 shows the process followed by the tool to detail the distribution of energy consumptions of buildings' stock. The benchmarking method distributes whole energy consumptions on the end uses consumptions. Users could then obtain a potential list of improvements by specifying additional number of input data concerning the part of his buildings' stock he would improved.

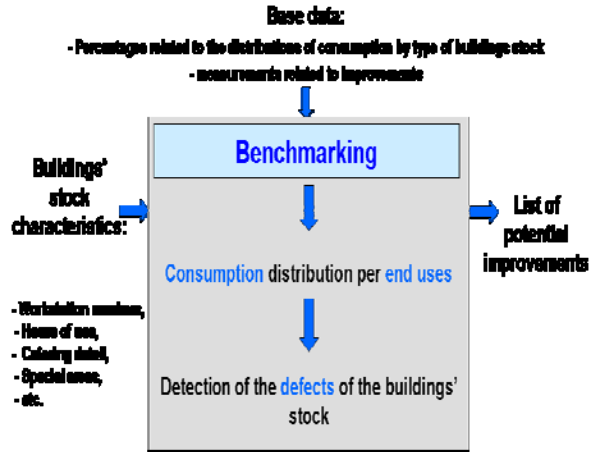

Figure 7: Step 2 (detailed benchmarking)

Figure 8 shows the results of a parametric study for the life cycle of the equipment according to the chosen improvements. The user of the tool has to define more inputs data required by the tool. Simulations will highlight the impacts of the improvements in terms of investment costs, return of investment costs and energy savings expected.

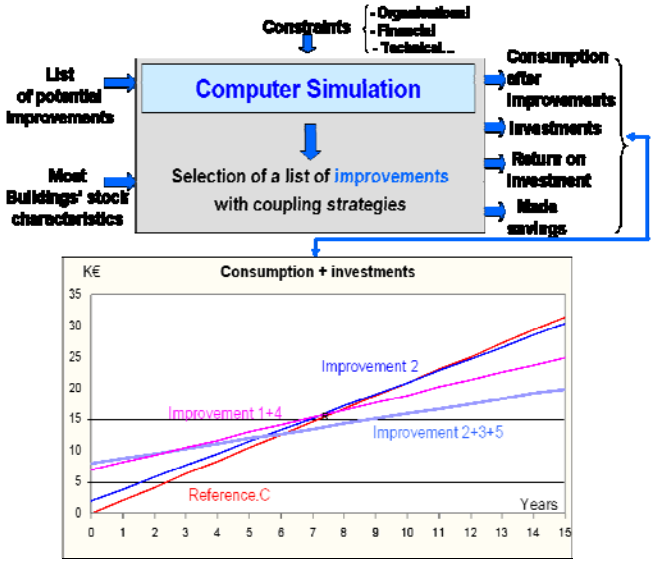

Figure 8: Step 3 (parametric study with computer simulation)

Figure 9 shows results of a comparison made by the tool. At this step, the benchmarking method compares:

- Energy consumptions obtained by simulation after the improvements,
- Real energy consumptions before the improvements,
- Reference energy consumptions.

This method evaluates also the impact of the improvements on the energy classification.

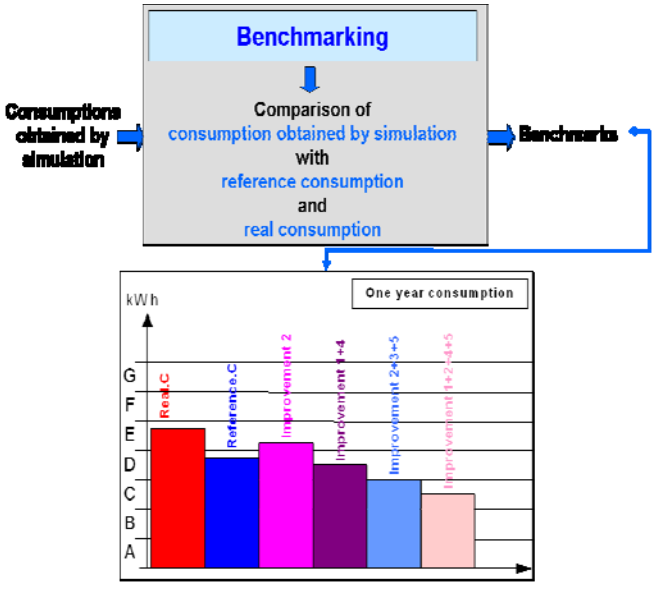

Figure 9: Step 4 (benchmarking after improvements)

Conclusion

This paper deals with the definition of the process and methodology of a tool for buildings stock manager. Its inputs are buildings stock characteristics, real consumptions and its uses. It gives a list of improvement and a list of possible coupling strategies according to the data bases and the constraints of the managers.

The future works of this study are twice:

- First, inquiries will continue with others managers in order to check and verify the development of the tool.
- Second, the first description of the aid decision-making tool will be developed in Matlab environment. This step is necessary to make suggestions to buildings stock manager. They will test it and correct it by making a default list.

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