ePlan 2006
Final Report

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SINTEF Building and Infrastructure
Architecture and building technology

April 2007
ABSTRACT

A prototype ePlan-model, focusing on the Norwegian building stock, has been implemented in the software tool LEAP (Long Range Energy Alternatives Planning System). The model is based on a historical analysis of energy consumption in buildings (E) and historical data on activity (A) defined as useful floor area for the different building categories. The historical intensity data is partly deduced from these numbers, partly based on previous research and partly on data from available sources such as the Enova Building Network. A major challenge has been to assure consistency when using different data sources and other sources of information, and some compromises have been made in order to obtain series of data with the same format to be used harmonically in the model.

The model has been demonstrated through development of four scenarios compared with a base scenario. One scenario focuses on substitution of electricity with thermal carriers. The results show that throughout a 30 year period, approximately 14 TWh of electric heating can potentially be replaced by thermal carriers compared to the base scenario although this would at the same time imply approximately 20 TWh increase in the use of thermal carriers. The remaining three scenarios focus on energy conservation measures with electricity as the main energy carrier. It is estimated that the application of moderate conservation measures both for new and renovated buildings, combined with the application of heat pumps, can reduce the use of electric energy with approximately 7 TWh and the use of thermal energy with approximately 10 TWh compared to the base scenario. The results also show that the potential for reducing energy consumption is higher for renovation activities than in new construction.
TABLE OF CONTENTS

1 ASSEMBLING THE DATA ........................................................................................................3
  1.1 ACTIVITY ...............................................................................................................................3
  1.2 ENERGY .................................................................................................................................3
  1.3 INTENSITY ............................................................................................................................4
  1.4 GROUPING ..............................................................................................................................4
  1.5 ACTIVITY, ENERGY AND INTENSITY IN 2005 .................................................................5
  1.6 COMPARING DERIVED AND EPBD INTENSITIES .............................................................7
2 STRUCTURE OF EPLAN MODEL .........................................................................................10
  2.1 ARCHETYPES .......................................................................................................................10
  2.2 SCENARIOS ........................................................................................................................10
  2.3 LEAP ...................................................................................................................................11
3 COMMON ASSUMPTIONS .....................................................................................................12
  3.1 HISTORICAL TRENDS ............................................................................................................12
  3.2 STOCK ................................................................................................................................13
  3.3 DEMOLITIONS, RENOVATIONS AND EXTENSIONS ..........................................................14
  3.4 NEW CONSTRUCTIONS ........................................................................................................20
  3.5 ACTIVITY, PAST AND FORECAST .......................................................................................21
4 SCENARIOS .............................................................................................................................25
  4.1 BASE SCENARIO ...................................................................................................................25
  4.2 SUBSTITUTION VS. CONSERVATION .................................................................................26
5 RESULTS ....................................................................................................................................29
6 DISCUSSION AND FUTURE WORK .....................................................................................35
REFERENCES .....................................................................................................................................37
APPENDIX 1 ........................................................................................................................................38
1 Assembling the data

From the separate reports on activity, intensity and energy, [1] [2] [3] respectively, all the gathered data were merged together for the development of the ePlan model. In doing this, the specific features of all data sources had to be taken carefully into account, because they all differ in some aspects. Some compromise had to be made in order to obtain, at the end, three series of data that had the same format and so could be used harmonically in the model. The following is a summary of decisions taken with a brief motivation.

1.1 Activity

Floor area is the only activity parameter in the current ePlan model. However, the floor area reported in different data sources can be defined differently. The most important definitions are:

<table>
<thead>
<tr>
<th>Appellation</th>
<th>Brief description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Utility floor space</td>
<td>The total utility floor space is the sum of the area within the outer walls for all floors. In a dwelling building for instance, the basement area will be a part of the utility floor space. The utility floor space is defined in the Norwegian Standard NS 3940 Area and volume calculations.</td>
</tr>
<tr>
<td>Useable floor space</td>
<td>The useful floor area is defined as the total area inside the outer walls that are used for living.</td>
</tr>
<tr>
<td>Heated floor space</td>
<td>( = ) Useable floor space</td>
</tr>
</tbody>
</table>

In order to have a unique and self-coherent data the GAB-Infoland source was used. GAB provides data expressed as utility floor area \([m^2]\) for both the residential and service sectors, and are available for the period 1983-2005. Data on the stock before year 1983 are weak: only 39% in residential and 14% in services available. It was assumed that all buildings before 1983 have the same average characteristics of these known portions.

1.2 Energy

Data on energy refer to delivered energy, see Figure 1-1. Delivered energy is defined as the net energy needed to cover the demand plus the eventual losses in the buildings energy systems. These losses can be production losses, distribution (including storage and submission) losses and losses caused bye non-ideal regulation. The delivered energy can thus be expressed as:

\[
E_{\text{delivered}} = \frac{E_{\text{demand}}}{\eta_{\text{sys}}} \quad (1)
\]

where \(\eta_{\text{sys}}\) is the system efficiency given by
\[
\eta_{sys} = \eta_{production} \cdot \eta_{distribution} \cdot \eta_{regulation}
\] (2)

Data on the delivered electricity and thermal carriers to the two categories; residential and service, were collected from several sources (SSB, NVE, etc.) for the period 1993-2004 (2003 for thermal carriers). Furthermore, data were temperature-corrected against a normal year [3].

![Diagram](image)

**Figure 1-1** The object of study is the delivered energy.

### 1.3 Intensity

Data on intensity also refer to delivered energy and are expressed in \([\text{kWh/m}^2\text{y}]\) and are normalized over utility floor area. The final choice was to use a combination of intensities derived from data on activity and intensity \((I = E/A)\) for the absolute value and fuel share, and data from the EPBD [4] [5] for share of different energy services (more on this in 1.6). The derived intensities refer to average national data (as data on energy and activity are totals for the whole country), while EPBD intensities refer to the Oslo climate. This source of error is limited by the fact that the majority of the stock is placed either in Oslo or in the surrounding regions that have similar climate.

Another and more important challenge is that studies on intensities normally tend to express the results normalized over heated or useful floor area, and not utility floor area. Data from Enova were available, after re-elaboration, also normalized over utility floor area as reported in [2]. For a number of reasons though, it was decided not to use these data. The main reasons were that there were few buildings in most categories and that the average size of the buildings in the building network were considerably higher than the stock average, and thus not representative for the total stock [1]. Nevertheless, data for energy services share presented in the Norwegian EPBD proposals [4] [5] are obtained also taking into consideration statistics from the Enova buildings network.

### 1.4 Grouping

According to the GAB register 3-digits code the various buildings categories were grouped up in seven major categories as shown in Table 1-1.
Table 1-1  Grouping of building categories.

<table>
<thead>
<tr>
<th>GAB code</th>
<th>Building category</th>
<th>Group category</th>
<th>Sector</th>
</tr>
</thead>
<tbody>
<tr>
<td>11x – 13x</td>
<td>Residential, small house</td>
<td>Small house</td>
<td>Residential</td>
</tr>
<tr>
<td>14x – 15x</td>
<td>Residential, apartments block</td>
<td>Apartments block</td>
<td></td>
</tr>
<tr>
<td>16x</td>
<td>Holiday house</td>
<td>Holiday house</td>
<td></td>
</tr>
<tr>
<td>17x – 19x</td>
<td>Residential Garage and similar</td>
<td></td>
<td></td>
</tr>
<tr>
<td>2xx</td>
<td>Industry, Agriculture and Fishery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>31x</td>
<td>Office</td>
<td>Office</td>
<td>Service</td>
</tr>
<tr>
<td>32x</td>
<td>Shop</td>
<td>Commercial</td>
<td></td>
</tr>
<tr>
<td>5xx</td>
<td>Hotel and Restaurant</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6xx</td>
<td>Education, Culture, Sport, Religious</td>
<td></td>
<td>Social</td>
</tr>
<tr>
<td>7xx</td>
<td>Hospital and Nursery</td>
<td></td>
<td></td>
</tr>
<tr>
<td>4xx</td>
<td>Transport and communication</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8xx</td>
<td>Prison and emergency prep.</td>
<td>Other</td>
<td></td>
</tr>
<tr>
<td>9xx</td>
<td>Other</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

The reasoning for such grouping depends on the format and the grouping in which the data were available for activity and energy. As the two input data – activity and energy – were not grouped the same way, some adjustment was necessary. Appendix 1 gives the details of how energy for electricity and thermal carriers was allocated to the category groups. Finally it shall be noticed that the category residential garages were excluded from the analysis because it consumes virtually no energy. Likewise the category consisting of buildings for industrial, agricultural and fishery purposes were excluded since their energy consumption mainly depend on the agricultural and industrial activities rather than the buildings’ energy performance.

1.5  Activity, Energy and Intensity in 2005

According to the grouping above, data on activity and energy appear like in Figure 1-2 and Figure 1-3. For simplicity only the graphs are presented here, while complete tables are available in attached spreadsheet Error! Reference source not found.. Values for year 2005 on energy were taken from a linear regression of the available series.
Figure 1-2 ACTIVITY, data refer to year 2005 (data are on utility floor area).

Figure 1-3 ENERGY, data refer to year 2005.

It is worth noticing that while concerning activity none of the categories apart “Small house” reaches a figure of 10% of the total stock. Considering the energy data the second most important category is “Other”. The category “Other” includes all building categories for which no information was available either on activity or energy or intensity (EPBD). This category is therefore an indicator of the uncertainty of these data. If better data become available this will reduce the uncertainty of the model. Intensity figures for year 2005 are obtained by dividing energy per activity: \( I = \frac{E}{A} \). Results are shown in Figure 1-4.
The column Other in Figure 1-4 gives a clear indication of the uncertainties that are implicit in the data available.

### 1.6 Comparing derived and EPBD intensities

As mentioned above, a combination of derived and EPBD intensities were used to build the ePlan model. EPBD intensities from the original building categories in [4] [5] were grouped by weighting them against the respective building category activities.

EPBD defines two reference values for each category. The regulation reference Rr (delimiting class C) establishes the reference values for new constructions. In this case the specific energy is meant to be obtained with systems that have a unitary efficiency; in other words, the required performance is to be met on the energy need. The stock reference Rs (delimiting class E) estimates values for the existing stock. In this case the specific energy is calculated by means of weighting factors on the delivered energy. These weighting factors are meant to promote some energy carrier, like gas or district heating, rather than others, like electricity or oil. Nevertheless EPBD [4] [5] also gives figures for Rs estimates on delivered energy before applying the conversion factors, and these values has been used in the model. They differ only slightly from the class E definition because the main carriers, electricity and oil, are weighted with a factor of one. Figure 1-5 shows the references Rr and Rs in the EPBD labelling system.
Rr, new regulation

Rs, average stock (before weighting factor)

Figure 1-5  EPBD references Rr and Rs.

In Figure 1-6 the two sources are compared. EPBD values appear always higher than derived intensities. The fact that EPBD refers to Oslo climate while derived values are national overall averages doesn’t give a clear indication of whether one source should look bigger or smaller than the other and how much. In reality that depends on the building mass distribution over different climate regions. Nevertheless the differences are too big to be justified only by climatic variations over the country. The main reason for the differences is the area against which the figures are normalized. As mentioned above, the derived intensities are normalized over utility floor area while EPBD intensities are normalized over heated floor area. As discussed in [1] the difference between utility and useful floor area can be significant, utility being always bigger than useful floor space. Furthermore, it was not possible to find a predictable factor to convert from utility to useful floor area.

Figure 1-6  Derived versus EPBD intensities.

As utility floor area figures is always bigger than useful floor area figures it appears clear why EPBD intensities look higher than those derived from activity and energy data. Another way to look at it is to invert the reasoning. Let’s suppose that EPBD intensities are perfect estimates of average performances found in the stock. Then, multiplying them by the relative activities expressed in heated floor area (unknown)
the results shall match exactly the total energy figures. So, knowing both EPBD intensities and total energy consumption the activity expressed in heated floor area can be estimated. Results are shown in Figure 1-7, where data utility and equivalent heated area figures are compared side by side.

![Figure 1-7 Utility versus equivalent heated activity.](image)

The groups “Holiday house” and “Other” have not been converted because no information was available in the EPBD on these categories.
2 Structure of ePlan model

This section presents the basic features of how the ePlan model is structured. The structure is based on two fundamental pieces: archetypes and scenarios.

2.1 Archetypes

An archetype is an abstract entity which is a statistical composite of the features found within a category of buildings in the stock. As mentioned in 1.3 a combination of derived and EPBD intensities was used. Derived data are used for the total intensity and the fuel share; EPBD data are used for the energy services share, as shown in Figure 2-1.

![Figure 2-1 Structure of an archetype.](image)

2.2 Scenarios

The archetypes are collected into hierarchical levels in order to represent the entire stock. The levels are in bottom up order:

- energy demand (basic archetype): fuel share and services share
- heating system: local or centralized (in the building)
- condition: belonging to the stock and with unchanged stock’s average characteristics, renovated or new
- building category: one of the seven groups defined in Table 1-1
- geographical scale: in this case Norway

Such stock structure is then repeated with the same form but different parametric values in order to create a set of scenarios, as shown in Figure 2-2.
The heating system level is actually not implemented in the current version of ePlan. The few data gathered on this kind of information were not good enough to be used; possibly further investigation, or a narrowed scope (for example only on residential sector), can make room also for analyzing this feature. As a consequence of this lack of information the scenario analysis could not take into consideration options like changing heating system in itself. It was still possible, though, to assume that when major renovation is applied to a building then also the heating system can be changed without particular restrictions.

### 2.3 LEAP

The software tool that was used to implement ePlan is LEAP (Long-range Energy Alternatives Planning system) [11]. To develop the model it was necessary to buy a license, but to look at the results it is enough to use the free of charge evaluation version of LEAP. The only limitation it has is that changes made on the model cannot be saved; but it is still possible to run the simulations with the actual parameters and explore the results. All input data are read from an excel file named AIE input.xls, which is needed to correctly run the simulation. Both this and all other files that are needed to run ePlan are included in ePlan 1.1.zip.
3 Common assumptions

A set of assumptions was made to constitute the common background for the scenario analysis. Mainly these assumptions relate to the activity; in other words the historical and forecasted evolution of the building mass. The scope of ePlan is 30 years ahead, so until year 2035, as year 2005 has been taken as the base year.

3.1 Historical trends

It is important to analyse historical trends in order to derive reasonable forecasts. As discussed in [1], data on buildings are available from the GAB register established in 1983, but statistics on new constructions have been carried by SSB since after World War II. Data on population instead date as far back as the XIII century, and SSB also provides a number of scenarios for population increase toward 2050 and also 2100. Trends on population are important because the number of inhabitants is one of the most important driving forces in determining the size of the stock. Nevertheless other factors are also influential. Figure 3-1 shows historical trend and forecast for population (as from SSB medium scenario) together with the share of people living in urban areas, and the share of new dwellings built in apartment blocks (instead of detached or row houses).

![Figure 3-1](image)

**Figure 3-1** Historical trends on: population, % of urbanization, % of new dwellings built in apartment blocks.

It appears clear that in the last hundred and fifty years the growth in population has been accompanied by an urbanization phenomenon. Nowadays the level of urbanization is high (almost 80%) and so it is hard to believe it will continue indefinitely at the same step until it has reached 100%; on the other hand it is also difficult to know when and where it will eventually stabilize. Nonetheless, the high rate of urbanization reached might have already given some signal of its influence.
Looking at the kind of dwellings that are built new every year, for example, it can be seen that in the last 15 years there has been a net change in the trend. Despite Norwegian well-rooted tradition of living in detached and row-wooden houses, the share of dwellings built new in the last years in apartment blocks has reached, with a swinging behaviour, a value of almost 50%. Another parameter available from statistics on population and housing is the number of persons per dwelling, as shown in Figure 3-2.

![Figure 3-2 Historical trends on: population, persons per dwelling.](image)

Due to the fact that household size has been decreasing and material welfare increasing at the same time (easier to afford a dwelling and live in smaller familiar nucleus), the average number of persons per dwelling has been constantly decreasing in the last century, even though with different speeds in different moments. Of course a number of factors are behind this kind of changes in social customs: the progress of economy, war periods and the discovery of oil in the North Sea, just to mention some. However, such analysis is out of the scope of this work and so considerations of this kind cannot be pushed further. The only driving force that is well defined in its forecast trend is the expected population.

### 3.2 Stock

Based on the above considerations the forecast for the stock and new constructions was tied to the trend of population. This means that instead of simply projecting into the future linear trends of past data series on activity (both on stock and new constructions) without any rationale at all, these trends were made dependant from the only driving force that is well known: the population. This was applied to both the residential and the service sector. It might be argued that in the service sector the correlation between square meters of building stock and population is less pronounced than in the residential sector while economic aspects more influential. Nevertheless
considering the population as the only driving force is better than not considering any driving force at all.

The assumption that was finally made was to keep the ratio of square meter per person (also named standard of living), for each building category, on the linear trend line (or linear regression) of the period from 1991 to 2005. The choice of this time frame, while the data are available from 1983, has to reasons. First, data on energy are available only from 1993 onward [2]; hence it makes sense also for the activity to choose a comparable time series, for coherence. Second, the data available both on \( m^2/\text{person} \) and on the other variables discussed in 3.1 present a significant break in the trend from the eighties to the nineties. To continue a linear trend on a variable means, mathematically, to keep its derivative constant. This operation was performed for each building category.

The forecast for the stock is then obtained multiplying figure on square meters per person by the total population. Again, this is done per each building category, while Figure 3-3 shows overall values for residential and service sectors.

![Figure 3-3](image)

**Figure 3-3** Historical trend and forecast for residential and service stock. Lines are broken in year 2005 to emphasize the separation between historical trend and forecast.

### 3.3 Demolitions, renovations and extensions

When coming to demolition, renovation and extension activities data sources hardly exist. On the other hand, for the purpose of ePlan modelling it is indispensable to have this kind of information. So, as a compromise between the two constraints, need of
data and lack of data, it was necessary to make some assumptions based on the best available information.

Information on demolition activity was derived from censuses [6] and statistics on new constructions [7]. The two sources present data that were collected in different ways, making some discrepancy unavoidable. The censuses give information on the total number of dwellings inhabited in the year they take place. They have been carried out every decade since 1946. The data on total stock were linearly interpolated in order to have annual values. From 1946 SSB statistics on the number of dwellings built new every year are also available. The two series of data are plotted in Figure 3-4. The blue line represents the interpolated stock where dots highlight the original values; the yellow line is the sum of interpolated stock plus yearly values on new constructions. Except from certain discrepancy in the first years, it can be assumed that the difference between the yellow and blue lines is an estimate of demolition activity.

Information on renovation is taken from data collected in the census of 2001 that are not published, but available on request [8]. Unfortunately the information available is not exhaustive, but no other data was found on renovation. Only three figures are given, that represent the total number of dwellings renovated in the periods before 1970, between 1970 and 1980, and after 1980. In total almost half of the stock has been renovated. When it is assumed that these totals are obtained in a linear fashion the time distribution looks like the green bars in Figure 3-4. To better understand the
meaning of these numbers it is worth resembling here how the information was asked to the people in the census of 2001. In [9] these definitions are found:

- Renovation is meant as “Extensive improvements and renovation is defined as major work that has been carried out to raise the standard of the dwelling”.
- Period of renovation refers to the last renovation, “Where renovation/improvements have been carried out in several rounds, the last round is specified”.

The fact that only the last renovation round is signalled can partially explain why the figure for the last period, after 1980, is way bigger than the others. Nevertheless it shall also be considered that 80% of dwellings have been built after 1946, see Table 3-1, and so it is reasonable that most of them have been renovated with “major work” only once since their construction.
Table 3-1  Dwellings’ stock per period of construction, as in census 2001 [6].

<table>
<thead>
<tr>
<th>Period of construction</th>
<th>Dwellings</th>
<th>%</th>
</tr>
</thead>
<tbody>
<tr>
<td>1900 or earlier</td>
<td>122 285</td>
<td>6 %</td>
</tr>
<tr>
<td>1901-1920</td>
<td>90 694</td>
<td>5 %</td>
</tr>
<tr>
<td>1921-1940</td>
<td>155 166</td>
<td>8 %</td>
</tr>
<tr>
<td>1941-1945</td>
<td>14 979</td>
<td>1 %</td>
</tr>
<tr>
<td>1946-1960</td>
<td>335 216</td>
<td>17 %</td>
</tr>
<tr>
<td>1961-1970</td>
<td>296 980</td>
<td>15 %</td>
</tr>
<tr>
<td>1971-1980</td>
<td>377 257</td>
<td>19 %</td>
</tr>
<tr>
<td>1981-1990</td>
<td>327 133</td>
<td>17 %</td>
</tr>
<tr>
<td>1991-2001</td>
<td>241 838</td>
<td>12 %</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td>1 961 548</td>
<td>100 %</td>
</tr>
</tbody>
</table>

Turning the data presented so far into annual values, the demolition and renovation activities appear like in Figure 3-5. Averaging the demolition activity in the period 1981 to 2005 (same interval for which data on renovation are available) gives a value of approx. 4 000 dwellings demolished per year. This corresponds to the 0.26% of the original building stock of 1980. These two figures are very similar to those presented in [10].
It shall be noticed that while the stock has been constantly increasing, demolition and renovation behaviour has changed over time. As the stock becomes older renovation activity increases, as it would be expected. But while renovation seems to increase together with an increasing stock, the same appears not to be true for demolitions. At the same time that renovation has been high, in the last 20 years, demolition has been low, despite the fact that the stock was bigger than before. It seems like renovation also acts as an alternative to demolition. Nevertheless it is difficult to draw clear conclusions based on data gathered in the census about renovation activities as the definition is quite vague. One uncertainty is whether the dwellings were actually renovated in a way that could make space for energy saving measures (intervention of roof and/or façades, substitution of windows, change of heating system including boiler and possible radiators and piping, and so on). Historical data from the census indicate that, on the average, approximately 42 500 dwellings have been renovated each year since 1980. However, in all ePlan scenarios presented in this report (see Chapter 4) it is conservatively assumed that the future renovation activity will be 20 000 dwellings per year.

In addition to demolition and renovation, also information on extensions to existing buildings was available from the GAB register, see [1]. This kind of information was useful not only in itself, but also as a proxy to better estimate renovation activity. Figure 3-6 shows the overall results for extensions registered for the residential and service sectors from 1983 to 2005.
It is assumed that extensions are brought to buildings most of the times during renovation. Hence there is a correlation between the two figures. As the trend of extensions has been nearly constant in the past 20 years, it was assumed that it would remain constant at 140 000 m²/year for the period of analysis, the coming 30 years. This corresponds to approximately 4000 dwellings being extended each year, which corresponds to 1/5 of the dwellings assumed to be renovated.

When moving to the service sector, instead, no information was found except for the extension activity; but again, some sort of guess was needed to proceed with the analysis. Knowing that severe prudence is compulsory when transporting assumptions from the residential to the service sector, the following was applied: The demolition activity was assumed to be similar to the residential sector, see Table 3-2 for details. It is generally considered that service buildings have a faster turn over than residential ones; so to keep the demolition rate on similar values is likely to be a conservative assumption in the sense that it would not overestimate the demolition activity. The number of buildings renovated in the service sector was for the same reason set to 2.5 times the number of buildings extended (recall that for the residential sector the number of buildings renovated was assumed to be 5 times the number of buildings extended).

All the assumptions used in the model for demolition, renovation and extension activities are summarized in Table 3-2, but one more hypothesis has to be explained before to get the entire picture. It is that all demolished or renovated buildings were either built or renovated 30 years back in time. This means that, in the analysis of historical data, buildings demolished or renovated before the base year 2005 were...
assumed to have the same characteristics (as for example average floor area) as the stock in year 1982.

In the forecast analysis, it is assumed that all buildings demolished and renovated belong to the average stock of the base simulation year 2005. The data for forecast were based on average of the period 1991 to 2005 for coherence with the stock analysis in 3.2. All these operations were applied at the building category level while the results shown in Table 3-2 are the summary for residential and service sector.

3.4 New constructions

Once that the stock and all other activities have been defined, the activity for new constructions in each year \( i \) is derived by the following formula:

\[
\text{New}^i = \text{Stock}^i - \text{Stock}^{i-1} - \text{extension}^i + \text{demolition}^i
\]

The results are shown in Figure 3-7. The wavy behaviour is the effect of variations in the population growth.

---

**Table 3-2 Assumptions for demolition, renovation and extension activities.**

<table>
<thead>
<tr>
<th></th>
<th>Residential</th>
<th>Service</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>dwellings/year</td>
<td>m²/year</td>
</tr>
<tr>
<td>Historical data, 1991-2005</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demolition</td>
<td>4 000</td>
<td>≅ 550 000</td>
</tr>
<tr>
<td>Renovation</td>
<td>42 503</td>
<td>≅ 6 000 000</td>
</tr>
<tr>
<td>Extension</td>
<td>4 160</td>
<td>≅ 140 000</td>
</tr>
<tr>
<td>Forecast data, 2006-2035</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demolition</td>
<td>4 000</td>
<td>≅ 580 000</td>
</tr>
<tr>
<td>Renovation</td>
<td>20 000</td>
<td>≅ 3 000 000</td>
</tr>
<tr>
<td>Extension</td>
<td>4 160</td>
<td>≅ 140 000</td>
</tr>
</tbody>
</table>

\(^a\) CORRESPONDS TO APPROXIMATELY 5 TIMES THE NUMBER OF DWELLINGS EXTENDED

\(^b\) corresponds to approximately 2,5 times the number of buildings extended (calculation were done for each building category)
3.5 Activity, past and forecast

According to the trends observed in 3.1 we see that in the forecasted period 2005-2035 the increase in standard of living (m² per person) will not be a driving force as important as it has been in the period 1982-2005 (violet area). This is mainly a direct consequence of the observed flattening of the curve persons per dwelling, see Figure 3-2, and the increased share of apartment blocks due to their reduced average size compared to detached houses, see Figure 3-1.

Figure 3-8 and Figure 3-9 show past and future trends in the residential sector. Figure 3-10 and Figure 3-11 show, instead, the same profile but subdivided per condition of dwellings, which is the basic input parameter for the activity in the ePlan model.
Figure 3-8  Residential stock evolution from 1982 to 2005, per driving force.

Figure 3-9  Residential stock forecast from 2005 to 2035, per driving force.
Figure 3-10 Residential stock evolution from 1982 to 2005, per condition of dwelling.

Figure 3-11, indeed, represents graphically the inputs given to the model during the simulation. The three possible conditions for general unity of m² in the model are (see Figure 2-2):

- unchanged from the original stock
- renovated from the original stock (includes also extensions)
- built new after 2005

It can be noticed the significant reduction in renovation activity from Figure 3-10 to Figure 3-11 is due to the hypothesis, in forecasting, that only half of the registered buildings renovated (20 000 instead of 42 500) is considered as an opportunity for energy improvements.

Finally, the same graph is shown in Figure 3-12 for the service sector forecast. Here we see that the significance of renovation activity is reduced even more by the conservative hypothesis made (renovation activity equivalent to 2.5 times the extensions instead of 5 times).
Figure 3-11  Residential stock forecast from 2005 to 2035, per condition of dwelling.

Figure 3-12  Service stock forecast from 2005 to 2035, per condition of dwelling.
4 Scenarios

The hypotheses that define the different scenarios are briefly presented in this chapter. In all scenarios it is assumed that only buildings built new and those renovated can possibly contribute to change the patterns of energy consumption. In the base simulation year the complete stock belongs to the condition-group called stock unchanged. As the time evolves a certain number of square meters leave this group to migrate into the renovated group, according to the renovation flow defined in 3.3. At the same time an additional part is added to the renovated group because of extensions, while a small share of the stock is taken out to account for demolition. The group new also grows with time.

The data on activity are the same for all scenarios, as defined in the previous Chapter 3. Data on intensities for the base scenario are derived in a way that the resulting total energy demand matches the data collected in [3]. In the other scenarios intensities are forecasted according to the relative scenario’s assumptions. All the necessary input come from previous reports [1], [2] and [3].

4.1 Base scenario

In order to create a base for comparison of all others, a base scenario was defined. This is not meant to represent a realistic evolution of the building stock and its energy consumption; neither is it necessarily meant to represent a business as usual scenario. It is merely a base against which to compare the potential effects of the policies implemented in the other scenarios. The intensities for the base year of simulation, 2005, are calculated for each building category with a linear regression on the available data series, from 1993 to 2004. The same applies to carriers share. For all the simulation years intensities and carriers share are kept “frozen” at 2005 values, as shown in Figure 4-1 for the case of small houses.

In the base scenario it is made the hypothesis that buildings belonging to the renovated group continue to behave the same way as the stock unchanged group. In other words, renovation takes place in that amount of square metres but does not improve or worsen the energy performance of buildings. New buildings in the base scenario are built according to specification from EPBD, so with a demand for delivered energy equal to the limit of class C; the share of carriers – electricity and thermal carriers – remains the same as in the stock unchanged group.
4.2 Substitution vs. Conservation

In the other scenarios two different strategies were considered: substitution of electricity with thermal carriers and energy conservation that, instead, relies on electricity as the main carrier. Table 4-1 summarizes synthetically the hypotheses behind the scenarios. It shall be remembered, see Figure 2-1, that archetypes are defined by both energy carriers and energy services. The two definitions are independent in the structure of the model, but it is obvious that they are interrelated. For example, the maximum amount of thermal carriers used by an archetype corresponds to its (delivered) energy demand for thermal service. On the other hand, electricity can be used to supply both thermal and electric specific needs. The energy services are specified as equipment, lighting, fan (electric specific services) and hot water and temperature dependent (thermal services).

The scenario “Thermal carriers” is the only one that explores the effects of purely substituting electricity with thermal carriers to satisfy the thermal demand. It shall be remembered that in Norway most of the thermal load in buildings is met by electricity (for historical reasons of low-cost and abundant availability that are not longer valid nowadays). For example, data collected in [3] shows that for the category of small houses the share of electricity is as high as 71%, while only 26% of the energy need is electricity specific (the remaining 74% being heating and hot water needs). In this scenarios renovated and new buildings do not change their overall energy performances with respect to the base scenarios. The carriers used to satisfy such
demand though are different. In both renovated and new buildings all the thermal demand (heating + hot water) is fully met by thermal carriers.

**Table 4-1** Summary of main hypotheses for the scenarios.

<table>
<thead>
<tr>
<th>Scenario</th>
<th>Carriers</th>
<th>STOCK unchanged</th>
<th>RENOVATED</th>
<th>NEW</th>
</tr>
</thead>
<tbody>
<tr>
<td>Base</td>
<td>“frozen” at trend 1991-2004</td>
<td>as measured</td>
<td>no change</td>
<td>as new regulation</td>
</tr>
<tr>
<td></td>
<td><em>EPBD equivalent class</em></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td><em>E (Rs)</em></td>
<td><em>E (Rs)</em></td>
<td><em>C (Rr)</em></td>
</tr>
</tbody>
</table>

**Substitution of electricity with thermal carriers**
Extra-costs are on the hydronic heating system (pipes, radiators, boiler…)

<table>
<thead>
<tr>
<th>Thermal carriers</th>
<th>District Heating = Gas = Biomass = 33% each</th>
<th>idem</th>
<th>as Base + • thermal carriers supply</th>
<th>as Base + • thermal carriers supply</th>
</tr>
</thead>
</table>

**Conservation of energy with electricity as main carrier**
Extra-costs are on the conservation measures (window, insulation, ventilation…) and/or Heat pump

<table>
<thead>
<tr>
<th>Ren+ carriers supply as in Base</th>
<th>as Base + • reduced thermal demand (class D)</th>
<th>as Base</th>
</tr>
</thead>
<tbody>
<tr>
<td>Heat Pump</td>
<td>as Base + • Heat Pump</td>
<td>as Base + • Heat Pump</td>
</tr>
<tr>
<td>Low-E</td>
<td>as Base + • reduced thermal demand (class D)</td>
<td>as Base + • reduced thermal demand (class B)</td>
</tr>
<tr>
<td></td>
<td>• Heat Pump</td>
<td>• Heat Pump</td>
</tr>
<tr>
<td></td>
<td>• efficient electric appliances</td>
<td>• efficient electric appliances</td>
</tr>
</tbody>
</table>

For the sake of ePlan modelling itself it is virtually unimportant what kind of carrier is actually used, as far as it is not electricity. Nevertheless, for possible further work on the supply side and for eventually calculating the corresponding EPBD energy class
(see weighting factors in 1.6) the following hypothesis can be adopted: The demand for thermal carriers generated by the building stock as a whole is supplied by an equal share, 33% each, by district heating, gas and biomass.

It should be noticed that as these changes apply only to new and renovated (with major work) buildings it is actually not a constraint what energy carrier is chosen and neither is the fact that the building must be equipped with an hydronic heating system. Eventually, when including costs associated with the different options, these will have to be different for each thermal carrier.

The other scenarios all explore the effect of possible energy conservation measures that rely on electricity as main energy carrier. This choice is not only to create a contrast with the other strategy of substitution. Mainly it is due to the consideration that there are implicit limits on investments, even though the cost analysis was not performed. The rationale is that as energy saving measures through passive solutions (insulation, windows, ventilation system and so on) create extra costs with respect to conventional construction and/or renovation praxis. As a consequence it is assumed that no funds is left for even more investments in a hydronic heating system (electric panels is the most conventional heating system in Norway).

The scenario “Ren+” analyses the potential of applying energy conservation measures in the renovated buildings only. New construction and general carriers share are kept the same as in the base scenario. The improvements in the renovated group regard only the temperature dependent: this is improved from the average stock value (ca. class E) to the value that is needed to meet the class D definition (measured on energy need). The other energy services are left unchanged, and so the share of energy carriers.

In the scenario “Heat pumps”, instead, no improvement is made in the amount of energy needed, but heat pumps are adopted in all renovated and new construction so that the final delivered energy results lower and it is all electricity. Heat pumps are supposed to have the average performance of air-to-air units.

Finally, the scenario “Low-E” has the following features: In both renovated and new constructions electric appliances, lighting and fans are low-energy consuming, the temperature dependent service (namely heating) is diminished in a way to allow for renovated buildings and new buildings to achieve values equivalent to class D and B respectively (measured on energy need). So, both groups are improved just one class with respect to the base scenario; this is considered to be a reasonable hypothesis. At last, the remaining energy need is supplied by heat pumps, so that, again, this scenario has a strong dependency on electricity.
5 Results
In this section the main results of the simulation are presented and commented. In the model implemented in LEAP, just for the sake of demonstration, also the industry sector was included in order to have a complete picture of the stationary demand of energy in Norway. Nevertheless, no hypothesis and no scenario were applied to the industry sector, and this will not be discussed further. Figure 5-1 shows the share of total energy demand between building and industry in the base scenario for the simulation period.

Figure 5-1  Base scenario: total stationary energy demand.

Figure 5-2 shows, inside the building sector and for the base scenario, how the total energy demand is divided between the three major sectors: residential, services and other.
The sector “other” is actually an indication of the uncertainty of the input data, see 1.5. It is clear also from this graph that this uncertainty is quite significant. Another way to look at the same result is presented in Figure 5-3 (note that the profile of the curve is exactly the same as in Figure 5-2). Here the total is divided by building’s condition group.

In the base simulation year all the stock, hence all the energy demand, belongs to the group stock unchanged. With time evolving in the model, new and renovated buildings gain an increased share of the total. Note that renovated square meters leave the group stock unchanged to migrate into the group renovated. Extra square meters
coming from extensions are also added to the renovated group, while demolished square meters completely leave the model. That is why the sum of stock unchanged and renovated groups do not give a constant line in time even though the two groups do consume the same energy per square meter (see 4.1) – because demolition activity is actually bigger than extension activity.

It appears that in the base scenario, the total energy demand of the renovated part of the stock is at the same level as in the new construction. This is a first indication that the potential lying in renovations is of the same order of magnitude as for new buildings. In Figure 5-4 this concept is analysed further. Here the results from all the scenarios are presented as a difference from the base scenario for the final year 2035, and distinguished by condition group.

![Figure 5-4](image)

*Figure 5-4  All Scenarios vs. Base in year 2035, per building’s condition.*

Obviously there are no differences for the stock unchanged group.

In all scenarios the changes due to intervention in the renovated buildings result in being (in absolute value) more important than those coming from new constructions. This is perhaps the most important result of the analysis. Even though data on renovation activity were weak and conservative assumptions were made (see 3.3) it appears clear that the potential lying in renovation is the most important.

The reason why the potential for improvement is bigger in renovation is that the renovation activity is comparable to the activity for new constructions (see Figure 3-11 and Figure 3-12 ), and that new buildings have to be built in accordance with the new building code, and therefore is expected to perform significantly better than the stock’s average already in the base scenario.

It sounds reasonable to think that some improvement would come from renovation activity in a natural way, without need for any particular policy, as to say in a business
as usual fashion. This feature is not captured in the base scenario, where the performance of renovated buildings does not change. Thus, not all the benefits related to renovation shown in Figure 5-4 should be considered as policy dependent. Nevertheless the figures presented give a quantitative indication of how much it is possible to gain from the renovation activity. Finally, the scenario “thermal carriers” presents increases from the base scenario because heating systems based on thermal carriers have a lower efficiency than those based on electricity. Figure 5-5 introduces to the analysis of the energy carriers.

![Figure 5-5 Base scenario: Buildings’ Energy demand, per energy carrier.](image)

In the base scenario the total energy consumption increases due to the increase of the building mass, while the share between electricity and thermal carriers remains by definition constant. Figure 5-6 shows the differences in the other scenarios with respect to the base case. These outcomes are another very important result of ePlan scenario analysis.
The “thermal carriers” scenario is the one that gives the best result when considering only saved electricity. The drawback is that it has to be paid by an even greater increase in the demand for thermal carriers, due to the lower efficiency of heating systems. In the “Ren+” scenarios savings are limited because only the performance of renovated group is modified, instead of both renovated and new as in the other scenarios, and because no heat pumps are used here. In the scenario “heat pump” the thermal carriers are substituted by electricity used in heat pumps. The total amount of electricity required at the end is still lower than in the base scenario. The COP effect of heat pumps has levelled off the otherwise increasing electricity demand due to substitution of thermal carriers. The scenario “Low-E” improves the achievements also in electricity savings because of the reduced thermal load and the more efficient electric equipment combined. Finally, Figure 5-7 gives an overall vision of how the total energy demand is calculated to be in the ePlan model in year 2035 in the different scenarios with respect to its initial value in 2005.
In the base scenario there is an expected increase of total energy demand coming from the building sector alone (not industry) of about 20 TWh/y by year 2035. Note that in the “Low-E” scenario there is almost no increase – less than 3 TWh/y – in the total energy demand. This is the result of a net decrease in thermal carriers demand of -6 TWh/y counter-balanced by an increase of +9 TWh/y for electricity demand, with respect to 2005 values.
6 Discussion and future work

From the experience gained in developing the ePlan model the following emerge as key points. About the model:

- data availability is limited and data matching between different sources was problematic
- the archetypes structure proved to be flexible
- use of LEAP facilitated the scenario analysis

About the results:

- quantifies the potential in lying in renovation
- quantifies pros and cons of diversification vs. conservation strategy

For future work it is needed:

- to facilitate data collection and calibration
- to add cost analysis in ePlan
- move toward an integrated demand–supply analysis (ePlan – Markal)
- to increase time resolution (month, week, day and hour in addition to year)
- enable the model to be used on regional level and integrate with PANDA

The integrated ePlan – Markal analysis is schematically plot in Figure 6-1 that shows how the results of ePlan could be used as input to Markal in terms of energy demand profile and a series of constraints, e.g. on the share of electricity.

Figure 6-1 Possible interaction between ePlan and Markal, input.

An example of possible output, instead, is shown in Figure 6-2, where one of the output graphs from the Markal analysis [12] is presented with superimposed a supposed cost column from ePlan.

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1 PANDA is a tool for analysis of regional development in Norway (see [http://www.pandagruppen.no/](http://www.pandagruppen.no/) for further information)
The possibility of integrating the two tools, ePlan and Markal, in order to achieve an integrated demand and supply energy analysis has been already discussed and presented in [13].
References

[4] NVE, Oppdragsrapport: Energimerking av boliger, Trine D. Pettersen (NBI), Lars Myhre (NBI), Tore Wigenstad (Sintef), Tor H. Dokka (Sintef), 2005.
[5] NVE, Oppdragsrapport: Energimerking av næringsbygg, Trine D. Pettersen (NBI), Lars Myhre (NBI), Tore Wigenstad (Sintef), Tor H. Dokka (Sintef), 2005.
[12] Markal analysis doc XXXXXX
Appendix 1

### Grouping electricity

<table>
<thead>
<tr>
<th>Year</th>
<th>Enebolig</th>
<th>Rekkehus</th>
<th>Block</th>
<th>Total</th>
<th>Total</th>
<th>Total</th>
<th>Total</th>
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<tbody>
<tr>
<td>1993</td>
<td>21,418</td>
<td>6,200</td>
<td>8,327</td>
<td>4,297</td>
<td>1,145</td>
<td>787</td>
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<td>22,592</td>
<td>6,528</td>
<td>4,177</td>
<td>4,438</td>
<td>1,204</td>
<td>803</td>
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<td>1995</td>
<td>22,573</td>
<td>6,513</td>
<td>4,209</td>
<td>4,798</td>
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<td>800</td>
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<td>891</td>
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<td>4,736</td>
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<td>699</td>
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<td>4,313</td>
<td>4,126</td>
<td>1,204</td>
<td>359</td>
<td>2,261</td>
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</table>

### Grouping thermal carriers

<table>
<thead>
<tr>
<th>Year</th>
<th>Enebolig</th>
<th>Rekkehus</th>
<th>Block</th>
<th>Total</th>
<th>Total</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>1993</td>
<td>7,439</td>
<td>1,409</td>
<td>405</td>
<td>2,085</td>
<td>1,177</td>
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