# Building Energy Conservation Measures (ECMs) Mixed Integer Programming

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## 1 Introduction

The building Energy Conservation Measure packages are retrofitting packages that can be applied to a vintage building. There are ECM conflicts and building compatibility constraints: for example, replacing existing lighting with LED upgrade is in conflict with T8 light bulb (0.7W/sf) upgrade (ECM conflict) and the single zone rooftop unit efficiency upgrade can only be used in small office or small retail buildings (building compatibility). Besides, each ECM package has a associated cost and thus the total budget is another constraint.

In this task, we aim to find the top $N$ best combinations of ECM packages for a given building that maximize the energy savings using dynamic constraint generation for each $i$-th best iteration.

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & -\sum_{i}^{n} s_i x_i \\
\text{subject to} \quad & x_i + x_j \leq 1,\ \forall < i, j > \in E_{conflict} && (1)\\
& x_i = 0,\ \forall i \in I_{incompatible} && (2)\\
& \sum_{i}^{n} c_i x_i \leq budget && (3)\\
& \sum_{i}^{n} e_i x_i \geq co2\_reduction && (4)\\
& \sum_{i}^{n} y_i x_i \leq payback\_years && (5)\\
& x_i \in \{0, 1\},\ i = 1, \ldots, n && (6)\\
& \sum_{i \in \hat{I}_{k-1}} x_i \leq \sum_{i}^{n} \hat{x}_i^{(k-1)} - 1. && (7)
\end{aligned}
$$

## 2 Formulation Explained

For a building with ECM conflicts $E_{conflict}$, incompatible ECMs $I_{incompatible}$, at the $k$-th iteration (for the $k$-th best solution), we solve for:

$$
\begin{aligned}
\underset{x}{\text{minimize}} \quad & -\sum_{i}^{n} s_i x_i \\
\text{subject to} \quad & x_i + x_j \leq 1,\ \forall < i, j > \in E_{conflict} && (1)\\
& x_i = 0,\ \forall i \in I_{incompatible} && (2)\\
& \sum_{i}^{n} c_i x_i \leq budget && (3)\\
& \sum_{i}^{n} e_i x_i \geq co2\_reduction && (4)\\
& \sum_{i}^{n} y_i x_i \leq payback\_years && (5)\\
& x_i \in \{0, 1\},\ i = 1, \ldots, n && (6)\\
& \sum_{i \in \hat{I}_{k-1}} x_i \leq \sum_{i}^{n} \hat{x}_i^{(k-1)} - 1. && (7)
\end{aligned}
$$

In the objective function, $s_i$ is the financial saving for the $i$-th ECM package. All variables ($x_i$) are binary (Constraint (6)), where 1 means "selected" and 0 means "not selected". Constraint (1) makes sure that two conflicting ECM packages cannot be selected together, where $E_{conflict}$ is a set of index pairs that are in conflict. Constraint (2) prevents the use of incompatible ECM packages for the given building. Constraint (3), (4), and (5) make sure that the selected ECMs meet the budge, CO2 reduction, and payback years requirements. Constraint (7) is dynamically generated at each iteration, which excludes the solution in the previous iteration, where $\hat{I}_{k-1}$ is the set of optimal indices calculated at the $(k-1)$-th step, and $\hat{x}_i^{(k-1)}$, $i = 1, ..., n$ are the optimal solutions for the $(k-1)$-th iteration.

The problem is implemented on both the GLPK-4.44 engine for Ruby and the Gurobi Solver for Python. Code is hosted at github.com/BILLYZZ.