Study of Energy Analysis for the Using of Heating and Rubbing Method for Recycling of Demolished Concrete

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Abstract: ***Buildings demand energy in their life cycle right from its construction to demolition. Studies on the total energy use during the life cycle are desirable to identify phases of largest energy use and to develop strategies for its reduction. In the present paper, a study of analysis of total consumed energy by whole process of heating and rubbing method for recycling of demolished concrete. The difference of ΔH between RAC and aggregate of same mass and moisture content can be quantified to obtain the impact of using RAP on energy and/or CO_2 as found in results. The energy consumption to heat/dry RAP and virgin aggregates of the same mass per ton of HMA and moisture content for mix discharge temperatures of 280, 300, and 320^0F, respectively. The difference in percentage indicates using higher percentage saves heating energy while using low percentage RAC consumes more heating energy, when compared to no RAC in HMA, for discharge temperatures of 280, 300, and 320^0F, respectively***

Keywords: RCA, CA, Concrete demolition, Sustainability, green concrete, service life design, reliability

1. Introduction

Earth’s natural resources have been exploited to a point where the availability of virgin aggregates (VA) is now scarce if not unrealizable in some states, requiring the material to be hauled for lengthy distances, and elevating the projects expenses. Furthermore, disposal problems have risen from excessive volume of construction and demolition waste (C&D) evolving into a drastic escalation of tipping fees for dumping refuse at a site. There is an acceptable solution to these problems. If old demolished concrete was crushed to acceptable sizes, removing impurities such as steel ties, PVC pipes, and rebar along the way, it could easily be utilized for road base material (Chini et al., 2001). Numerous other possibilities exist for the use of recycled concrete aggregate (RCA) such as for pipe bedding, drain fields, parking lots, highway shoulders, etc. Regardless of its use, by not throwing away demolished concrete at a landfill location, the amount of natural raw materials produced yearly could decline vastly. Concrete can be recycled by hauling the concrete debris to a permanent recycling facility for crushing and screening or it can be crushed and screened at the demolition site where the aggregate is reused when it is processed. The total benefit of concrete recycling could be assessed only through analyzing its economic and environmental impacts. Two major parameters that should be considered are the cost and energy consumption. Sometimes the cost and/or energy consumption for RCA are more than for virgin aggregate. This largely depends on the transportation distances. This study will compare the cost and energy consumption for production and transportation of virgin aggregate and RCA by giving different values for the transportation distances to show the impact of transportation on cost and energy consumption.

As per report of Hindu online of March 2007, India generates 23.75 million tons demolition waste annually. As per report of Central Pollution Control Board (CPCB) Delhi, in India, 48million tons solid waste is produced out of which 14.5 million ton waste is produced from the construction waste sector, out of which only 3% waste is used for embankment. Out of the total construction demolition waste, 40% is of concrete , 30% ceramic‟s, 5% plastics, 10% wood, 5%metal, & 10% other mixtures. As reported by global insight, growth in global construction sector predicts an increase in construction spending of 4800 billion US dollars in 2013. These figures indicate a tremendous growth in the construction sector, almost 1.5 times in 5 Years. For production of concrete, 70-75% aggregates are required. Out of this 60-67% is of coarse aggregate & 33- 40% is of fine aggregate. As per recent research by the Fredonia group, it is forecast that the global demand for construction aggregates may exceed 26 billion tons by 2012. Leading this demand is the maximum user China 25%, Europe 12% & USA 10%, India is also in top 10 users. From environmental point of view, for production of natural aggregates of 1 ton, emissions of 0.0046 million ton of carbon exist where as for 1ton recycled aggregate produced only 0.0024 million ton carbon is produced. Considering the global consumption of 10 billion tons/year of aggregate for concrete production, the carbon footprint can be determined for the natural aggregate as well as for the recycled aggregate. The use of recycled aggregate generally increases the drying shrinkage creep & porosity to water & decreases the compression strength of concrete compared to that of natural aggregate concrete. It is nearly 10- 30% as per replacement of aggregate. Recycling reduces the cost (LCC) by about 34-41% & CO2 emission (LCCO2) by about 23-28% for dumping at public / private disposal facilities.

Recycled concrete aggregate, or crushed concrete waste, is a feasible source of aggregates and an economic reality, especially where good aggregates are scarce. RCAs are aggregates derived from the processing of materials previously used in a product and/or in construction. Examples include RCA from C&DW and reclaimed aggregate from asphalt pavement. RCA is produced by crushing sound, clean demolition waste of at least 95% by weight of concrete, and having a total contaminant level typically lower than 1% of the bulk mass. Other materials that may be present in RCA are gravel, crushed stone, hydraulic-cement concrete or a combination thereof deemed suitable for premix concrete production. Conventional stone crushing equipment can be used, and new equipment has been developed to reduce noise and dust during the processing of RCA.

Sources of recycled concrete aggregate

Traditionally, concrete waste from the demolition of different construction projects is used for landfill, but nowadays RCA can be used as a new construction material or for the repair of existing structures. RCA is mainly produced from crushing concrete pavements, structures, buildings and bridges. The main reason for choosing structures, buildings and pavements as sources for RCA is because of the huge amount of crushed C&DW that can be produced from these sources.

2. Historical Background

Buildings consume energy directly or indirectly in all phases of their life cycle right from the cradle to the grave and there is interplay between phases of energy use (embodied and operating energy). Hence, they need to be analysed from life cycle point of view. Bekker [3] highlighted that in the building sector a life cycle approach is an appropriate method for analysis of energy and use of other natural resources as well as the impact on the environment. Later on Adalberth [4] presented a method describing the calculation of the energy use during the life cycle of a building. The method is applied to gain insight into the total energy use of dwellings in its life cycle in his companion paper [5]. The paper presented case studies of the total energy use for three single-unit dwellings built in Sweden wherein, it was reported that 85% of the total energy usage was required during the operation phase and energy used in manufacturing all the construction materials employed in construction with the erection and renovation amounts approximately to 15% of the total energy use. The transportation and process energy used during erection and demolition of the dwellings comprises approximately 1% of the total energy requirement. Several other similar studies are reported in the open literature for residential buildings [6–9] and office buildings [10–12]. Table 1 shows an abstract of data sources adopted by different authors to evaluate life cycle analysis of buildings. It is concluded from these case studies that operating energy has major share (80–90%) in life cycle energy use of buildings followed by embodied energy (10–20%), whereas demolition and other process energy has negligible or little share. Since operating energy of the buildings has largest share in life cycle energy distribution, reducing it appears to be the most important aspect for the design of buildings which demand less energy throughout their life cycle. Embodied energy should then be addressed in second instance. In order to reduce operational energy demand of the buildings, passive and active measures such as providing higher insulation on external walls and roof, using gas filled multiple pane windows with low emissivity (LE) coatings, ventilation air heat recovery from exhaust air, heat pumps coupled with air or ground/water heat sources, solar thermal collectors and building integrated solar photovoltaic panels, etc. were examined in life cycle perspective by many researchers. Mithraratne and Vale [13] recommended provision of higher insulation to a timber framed house situated in New Zealand as an energy saving strategy. Different versions of the same building with varying active and passive measures were also analysed [14–16]. It is observed that reductions in life cycle energy of the buildings over their conventional ones are proportional to the degree and number of energy saving measures used in the building. Conventional building refers to a building built according to the common practice of a specific country. However, reduced demand for operating and life cycle energy is achieved by a little increase in embodied energy of the building due to the energy intensive materials used in technical and other installations. Thormark [17] reported that embodied energy and its share in the life cycle energy for low energy building is higher than conventional ones. Though embodied energy constitutes only 10–20% to life cycle energy, opportunity for its reduction should not be ignored. There is a potential for reducing embodied energy requirements through use of materials in the construction that requires less energy during manufacturing [18]. While using low energy materials, attention must be focussed on their thermal properties and longevity as they have impact on energy use in other phases of a building's life cycle. Oka et al. [19] quantified energy consumption and environmental pollution caused by construction in Japan. Buchanan and Honey [20] made a detailed study on embodied energy of buildings and resulting carbon dioxide emissions with wood, concrete, and steel structures for office and residential purposes in New Zealand and concluded that wood constructions have less embodied energy than concrete and steel structures. Venkatarama Reddy and Jagadish [21] estimated the embodied energy of residential buildings using different construction techniques and low energy materials and obtained 30–45% reduction in embodied energy. Shukla et al. [22] evaluated embodied energy of an adobe house in Indian context. The house was constructed using low energy intensive materials like soil, sand, cow dung, etc. For the adobe house [22], about 50% reduction in embodied energy was observed.

Compared to a conventional concrete house. This reduction was achieved due to the use of low energy intensive and locally available materials (e.g. soil, sand, cow dung, etc.) compared to burnt clay bricks, concrete, cement, etc., in the concrete house. Another opportunity for reducing embodied energy is through use of recycling materials in the construction. Thormark [23] studied two cases: (i) the building which was built with a large proportion of reused materials and components; (ii) the building in which all materials and components had been new. The results showed that about 55% of energy could be saved with reused materials and components. Thus, it can be observed from the reported results that buildings can be made to demand low energy in their life cycle with passive and active measures as well as using low energy materials in the construction. Low energy buildings become sustainable constructions, provided most of its energy use for operation (electricity) is derived

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largely from renewable or low CO2 resources [24]. In order to directly address a set of specific environmental loads caused by buildings and their operation, researchers have increased the scope of analysis beyond pure energy accounting and applied a full life cycle assessment analysis in their studies [25–28]. Environmental impacts like global warming potential, acidification potential, and photo-oxidant formation potential are considered in these studies. Seo and Hwang [29] examined and estimated CO2 emissions in the entire life cycle of buildings. From these studies, it may be observed that the impact of different phases of the building on environment is similar to energy share of these phases in the life cycle energy of the buildings. LCA is much dependent on the primary sources of the energy of a particular place and conversion efficiency of materials production processes. If energy source is changed from fossil to renewable, environmental impact drastically changes. Also, it can be seen that the renewable sources of energy have less impact on the environment. There are also comparative life cycle assessment studies in the open literature; Marceau and VanGeem [30] presented life cycle assessment of a single-family house modelled with two types of exterior walls: wood framed and insulating concrete form (ICF). The house was modelled in five cities of different climates in US. The results showed that in almost all cases, for a given climate, the impact indicators are greater for the wood house than for the ICF house. Xing et al. [31] presented the life cycle assessment of office buildings constructed in China using steel and concrete. They observed that embodied energy and environmental emissions of steel framed building was superior to the concrete framed one. However, energy use and associated emissions were larger for steel framed building due to the higher thermal conductivity of steel than concrete. As a result life cycle energy consumption and environmental emissions of steel framed building were slightly higher. From the LCA studies of the buildings presented in the literature it can be concluded that impacts on the environment correlate closely with primary energy demand of the buildings in their life cycle.

3. Methodology

The primary objective of this research was to compare the cost and energy consumption for the three alternative methods used in handling concrete demolition waste and also to determine the best alternative for the disposition of the demolished concrete. A case was therefore created in which a four-story concrete structure is demolished. This theoretical building is located in Gainesville, Florida at the intersection of University Avenue and 13th Street. Three different demolition and disposal alternatives were examined. The first case considered was to crush the concrete at the demolition site using a portable crusher and to use the RCA as a base material at the same site. The second case considered was to dispose the demolished concrete at the nearest landfill and then buy new virgin aggregate from the nearest quarry. The third case considered was to dispose the demolished concrete at a concrete recycling plant and then to buy the RCA from the same recycling plant. The cost and energy consumption for all the three cases were determined. Data were collected by visiting the nearest concrete recycling plant and quarry.

Energy

The two major areas in which energy consumption was calculated were for crushing and transportation in all three cases. The energy consumption was calculated based on Building for Environmental and Economic Sustainability (BEES) Technical Manual and User Guide. According to BEES 4.0 (Lippiatt, 2007), the energy used in the production of crushed aggregate is 82 kJ/kg, and following Bonilla and Salling (2008), the energy required for the transportation of material for every 100 km is 265.5 kJ/kg. The energy consumption in the first case involves the energy for transporting the portable crusher to the jobsite and the energy for crushing the demolished concrete. The round trip distance from the recycling plant to the jobsite was 4.81 km. The total quantity of waste concrete required to be crushed by the portable crusher was 6,169 metric tons. Using these values, the total energy consumption in the first case was calculated (see Table 4). The energy consumption in the second case involves the energy consumed in transporting the waste concrete from the jobsite to the landfill, energy for transporting the virgin aggregate from the quarry to the landfill, and the energy for the production of virgin aggregate. The distance between the jobsite and the quarry pit was 24.7 km and the distance between the jobsite and the landfill was 26.5 km. Using these values, the total energy consumption in the case 2 was calculated (see Table 5). The energy consumption in case 3 involves the energy for transporting the waste concrete from the jobsite to the recycling plant, energy for transporting the recycled concrete aggregate from the recycling plant to the jobsite, and energy consumed in crushing the demolished concrete at the recycling plant. The distance between the jobsite and the recycling plant is 2.41 km.

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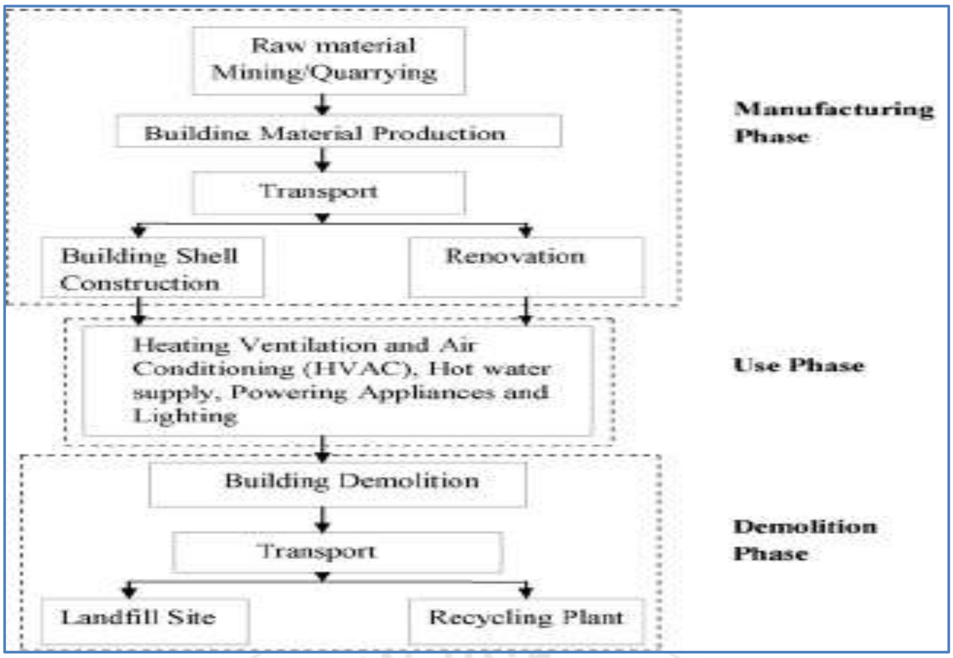

Figure 1: System boundaries for life cycle energy analysis

Embodied energy

Embodied energy is the energy utilized during manufacturing phase of the building. It is the energy content of all the materials used in the building and technical installations, and energy incurred at the time of erection/construction and renovation of the building. Energy content of materials refers to the energy used to acquire raw materials (excavation), manufacture and transport to Fig. 1. System boundaries for life cycle energy analysis. Embodied energy is divided in two parts: initial embodied energy and recurring embodied energy.

Initial embodied energy

Initial embodied energy of a building is the energy incurred for initial construction of the building. It is expressed as:

$$EE_i = \sum m_i \, M + E_{c_i} \qquad (1)$$

Where EEi = initial embodied energy of the building; mi = quantity of building material (i); Mi = energy content of material (i) per unit quantity; Ec = energy used at site for erection/construction of the building.

Recurring embodied energy

A large variety of materials are being used in building construction. Some of them may have a life span less than that of the building. As a result, they are replaced to rehabilitate the building. In addition to this, buildings require some regular annual maintenance. The energy incurred for such repair and replacement (rehabilitation) needs to be accounted during the entire life of the buildings. The sum of the energy embodied in the material, used in the rehabilitation and maintenance is called recurring embodied energy and can be expressed as:

$$EE_r = m_i M_i[(L_b/Lm_i) - 1] \qquad (2)$$

Where EE_r = recurring embodied energy of the building; L_b = life span of the building; Lm_i = life span of the material (i). Embodied energy largely depends on the type of the materials used, primary energy sources, and efficiency of conversion processes in making building materials and products.

Operating energy

It is the energy required for maintaining comfort conditions and day-to-day maintenance of the buildings. It is the energy for HVAC (heating, ventilation and air conditioning), domestic hot water, lighting, and for running appliances. Operational energy largely varies on the level of comfort required, climatic conditions and operating schedules. Operating energy in the life span of the building is expressed as:

$$OE = E_{OA}L_b \qquad (3)$$

where OE = operating energy in the life span of the building; E_{OA} = annual operating energy; L_b = life span of the building.

Demolition energy

At the end of buildings' service life, energy is required to demolish the building and transporting the waste material to landfill sites and/or recycling plants. This energy is termed as demolition energy and expressed as:

$$DE = ED + ET \qquad (4)$$

where DE = demolition energy; ED = energy incurred for destruction of the building; ET = energy used for transporting the waste materials.

Life cycle energy (LCE)

Life cycle energy of the building is the sum of the all the energies incurred in its life cycle. It is thus expressed as:

$$LCE = EEi + EEr + OE + DE \qquad (5)$$

Energy savings from recycling or reusing the demolished building materials is not considered in the life cycle energy estimation of the buildings. This is primarily due to the fact that there is no common agreement over attributing this saved energy to the demolished building. However, it would be more appropriate if this energy from recycling or reusing is incorporated in the life cycle energy estimation in overall sense. Studies on the life cycle energy use of the building are desirable, to evaluate strategies for reduction in energy requirement of the buildings. By performing life cycle energy analysis, the phases that have highest energy demand can be identified and targeted for improvement. Life cycle energy, if quantified in terms of primary energy can give a useful indication of the greenhouse gas emissions attributable to buildings and therefore its impact on the environment. However, for broader environmental impact analysis, life cycle assessment (LCA) of buildings is useful.

4. Results

Table 1: Energy Analysis of Heating/Drying RAC and Virgin Aggregate (Per Ton of HMA) for Discharge Temperature of 280^{0}F

RA content	Moisture Content	Discharge Temperature	Ambient Temperature	Energy to heat/dry RAC	Energy to heat/dry Aggregate	Difference in Energy	Difference In Percentage
0	3	280	60	35131	18990	16141	85.00%
25	3	280	60	50926	37979	12947	34.09%
50	3	280	60	67125	56969	10155	17.83%
75	3	280	60	81443	75959	5485	7.22%
100	3	280	60	91599	94949	-3350	-3.53%

Table 2: Energy Analysis of Heating/Drying RAP and Virgin Aggregate (Per Ton of HMA) for Discharge Temperature of 300^{0}F

RA content	Moisture Content	Discharge Temperature	Ambient Temperature	Energy to heat/dry RAP	Energy to heat/dry Aggregate	Difference in Energy	Difference In Percentage
0	3	300	60	43907	20064	23843	118.84%
25	3	300	60	59570	40128	19442	48.45%
50	3	300	60	75845	60192	15653	26.00%
75	3	300	60	90268	80256	10012	12.48%
100	3	300	60	100377	100320	57	0.06%

Table 3: Energy Analysis of Heating/Drying RAP and Virgin Aggregate (Per Ton of HMA) for Discharge Temperature of 320^{0}F

RA content	Moisture Content	Discharge Temperature	Ambient Temperature	Energy to heat/dry RAP	Energy to heat/dry Aggregate	Difference in Energy	Difference In Percentage
0	3	320	60	52683	21138	31545	149.23%
25	3	320	60	68214	42277	25938	61.35%
50	3	320	60	84565	63415	21150	33.35%
75	3	320	60	99093	84553	14540	17.20%
100	3	320	60	109156	105691	3464	3.28%

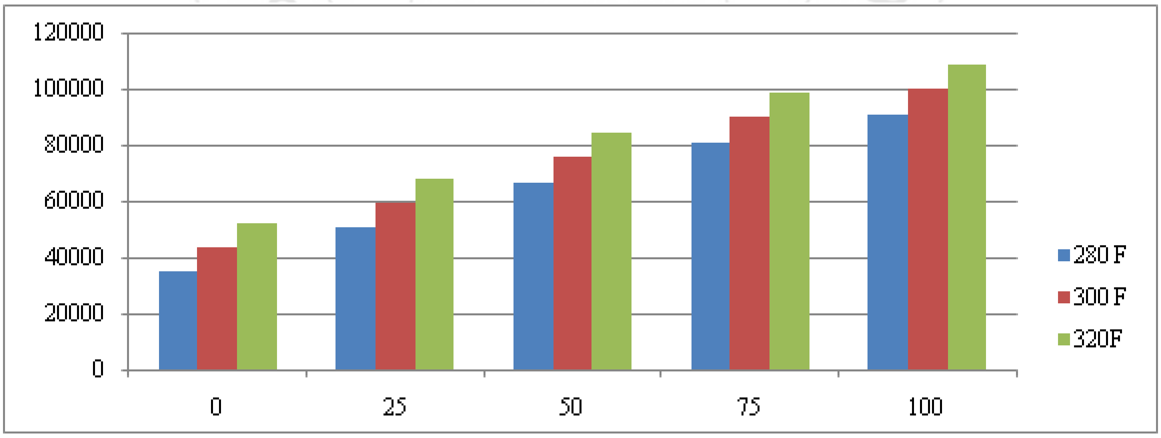

Figure 2: Energy Analysis of Heating/Drying RAC and Virgin Aggregate (Per Ton of HMA) for Discharge Temperature of 280^{0}F

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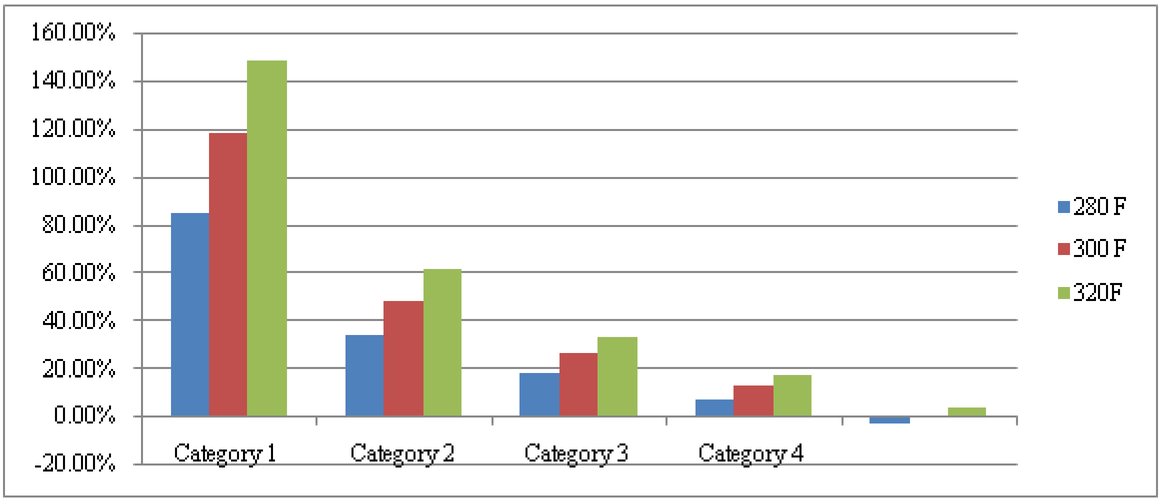

Figure 3: Energy Analysis of Heating/Drying RAC and Virgin Aggregate (Per Ton of HMA) for Discharge Temperature of 300^0F

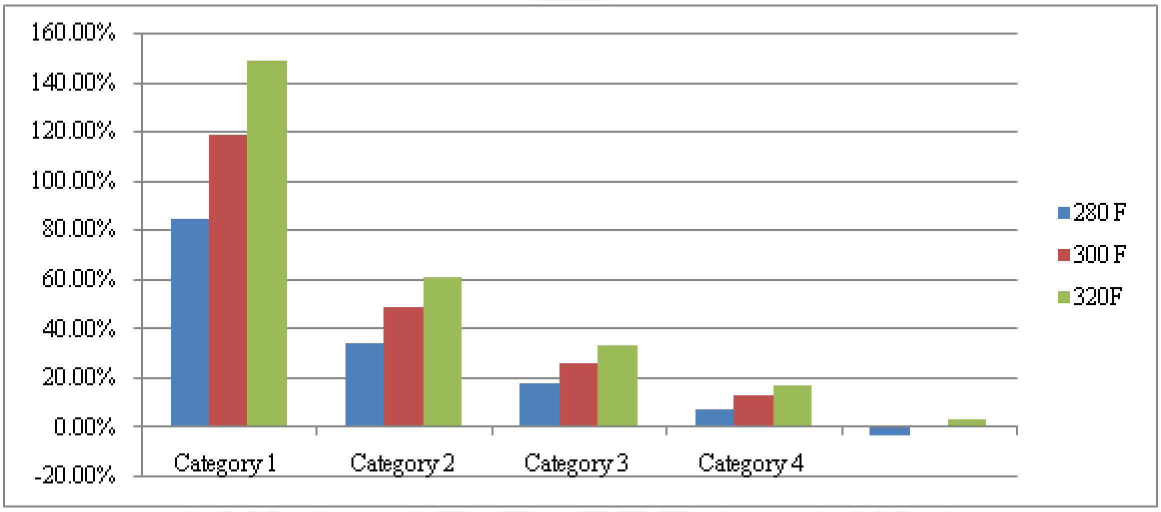

Figure 4: Energy Analysis of Heating/Drying RAC and Virgin Aggregate (Per Ton of HMA) for Discharge Temperature of 320^0F

The difference of ΔH between RAC and aggregate of same mass and moisture content can be quantified to obtain the impact of using RAP on energy and/or CO_2. Table 4.12, 4.13, and 4.14 shows the energy consumption to heat/dry RAP and virgin aggregates of the same mass per ton of HMA and moisture content for mix discharge temperatures of 280, 300, and 320^0F, respectively. The difference in percentage indicates using higher percentage saves heating energy while using low percentage RAC consumes more heating energy, when compared to no RAC in HMA, as illustrated in Figures 4.16, 4.17, and 4.18 for discharge temperatures of 280, 300, and 320^0F, respectively.

5. Conclusions

The analysis of cases found in literature showed that life cycle energy use of buildings depends on the operating (80–90%) and embodied (10–20%) energy of the buildings. Normalised life cycle energy use of conventional residential buildings falls in the range of 150–400 kWh/m2 per year (primary) and office buildings in the range of 250–550 kWh/m2 per year (primary). Building's life cycle energy demand can be reduced by reducing its operating energy significantly through use of passive and active technologies even if it leads to a slight increase in embodied energy. Therefore, crushing waste concrete at the demolition site where the aggregate is reused is the most economic and energy efficient option. The results of this study also showed that the transportation distance has a major impact on cost and energy consumption. When the distance between the jobsite and the recycling plant was increased at the increments of 5 km, there was a point at which virgin aggregate became a more favorable option in terms of cost and/or energy consumption than using a RCA from a recycling plant.

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